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1939/41

Transactions of the Academy of Science of St. Louis

30
1939-41

VOLUME XXIX

TITLE PAGE AND INDEX

JUNE, 1935

TO

JULY, 1938

Published Under Direction of the Council

Academy of Science of St. Louis

Founded 1856

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VOLUME XXIX, No. 1.

Natural History of the Alligator Lizards

HENRY S. FITCH

Issued June 30, 1935

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VOLUME XXIX, No. 1.

Natural History *of the* Alligator Lizards

HENRY S. FITCH

Issued June 30, 1935

Natural History of the Alligator Lizards

HENRY S. FITCH

Museum of Vertebrate Zoology,
University of California

INTRODUCTION

In 1931, I undertook a systematic revision of the Alligator Lizards (*Gerrhonotus*). During the course of my study of the forms inhabiting the Pacific Coast region, field work was done in Oregon and California. It has seemed advisable to incorporate the natural history observations made at that time in a separate paper as here set forth.

I have personally made observations and taken specimens in Wasco, Lane, Coos, Klamath, Jackson, Josephine and Curry counties in Oregon, and in Siskiyou, Shasta, Trinity, Humboldt, Tehama, Nevada, Eldorado, Amador, Alameda, Contra Costa, San Francisco, San Mateo, Santa Cruz, and Fresno counties in California. Many of the observations here included were made in the vicinity of my home near Medford, Jackson County, Oregon, and at Daly City, San Mateo County, California.

Many friends contributed material and information used in this paper. I am especially grateful to Doctors Joseph Grinnell and Jean M. Linsdale whose counsel and suggestions have proved frequent aids.

A brief explanation of the systematic status of the forms discussed will be given. (See also Fitch, 1934a and 1934b.) Two distinct species, *Gerrhonotus coeruleus* and *Gerrhonotus multicarinatus* occur in the region studied. *G. coeruleus* is found in its typical form only in the coastal region of central California, from Monterey County to Sonoma County. In Sonoma County it intergrades with *G. c. shastensis,* which ranges north along the coast to Humboldt Bay, and northeast in mountainous regions around the nortern end of the Sacramento Valley to the Lassen Peak region and to Lake County, Oregon. *G. c. palmeri* is restricted to the Sierra Nevada of California, while *G. c. principis* occurs along the Oregon and Washington coasts, north into British Columbia, and northeast into Montana.

G. multi-carinatus is found in its typical form from Ventura County to Mendocino County along the central California coast, and throughout the Sacramento Valley. In the north, its subspecies *G. m. scincicauda* occurs in western Oregon and northwestern California. *G. m. webbii* occurs on the west side of the Sierra Nevada, and south through the Sierra San Pedro Mártir of Lower California.

In life zone *multi-carinatus* is typically Upper Sonoran but overlaps into both Lower Sonoran and Transition. *G. coeruleus* is typically a Transition Zone species. Three of the subspecies occur frequently in the Canadian Zone but apparently none is ever found in Upper Sonoran. The ranges of the two species overlap at many points, but, even though in some localities both are abundant, they are in the main complementary in distribution.

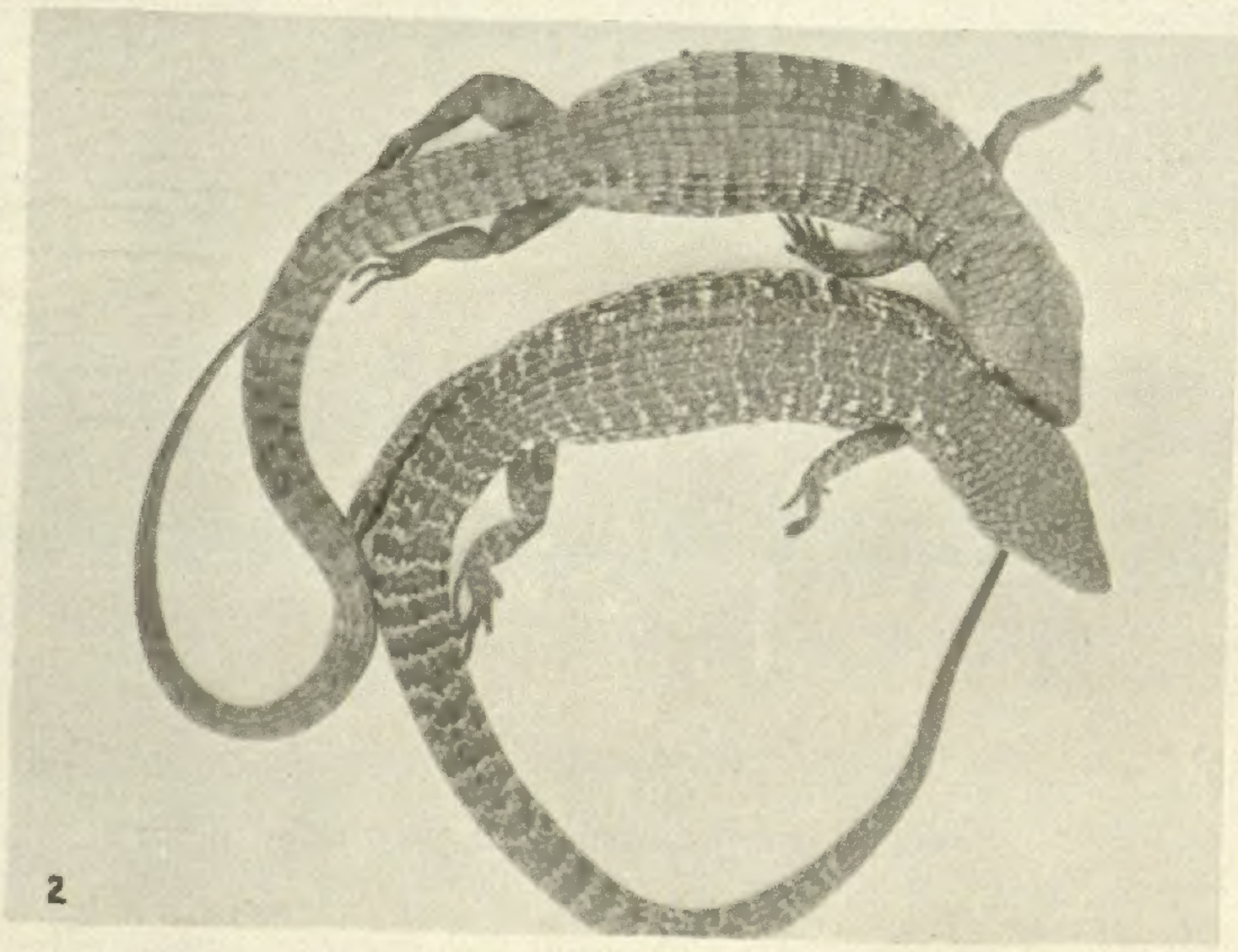
Interspecific competition may be severe in the few places where both are abundant, as their food preferences are similar. However, in keeping with its larger size, *multi-carinatus* occasionally feeds upon large prey which could not be killed or swallowed by *coeruleus*. Several times I have seen an adult *coeruleus* in captivity catch and kill a large Jerusalem cricket, then struggle for half an hour or more in an endeavor to engulf the prey, and finally give up in exhaustion.

G. multi-carinatus is oviparous and deposits eggs which require several weeks to hatch. *G. coeruleus* is ovoviviparous and brings forth fully developed young. Available data indicate that the number of eggs laid by *multi-carinatus* is considerably larger than the number of young produced by *coeruleus*. Eggs left in the ground are exposed to the attacks of numerous egg-eating reptiles, mammals, and insects, and to extremes of temperature and danger of desiccation, while those carried by the female are partly protected from these dangers and probably stand a better chance of developing into independently successful young.

Within several groups of reptiles it seems to be true that those forms occurring in relatively cold and damp climates are viviparous while closely related forms, occurring farther south or at lower altitudes, are oviparous. Gadow (1913:52) in discussing the evolutionary tendencies in a high altitude environment concludes from his observations on Mexican reptiles: "Another result seems to be that many cold-blooded vertebrates have given up the laying of eggs which might not be hatched on the clammy ground, and have become viviparous, undoubtedly a safer mode of looking after the welfare of their kind".

Viviparity in *coeruleus* may have originated in response to such environmental influences since two subspecies occur at high altitudes, and another ranges far north where climatic conditions are nearly equivalent. Eggs laid in a spot sufficiently

PLATE I.



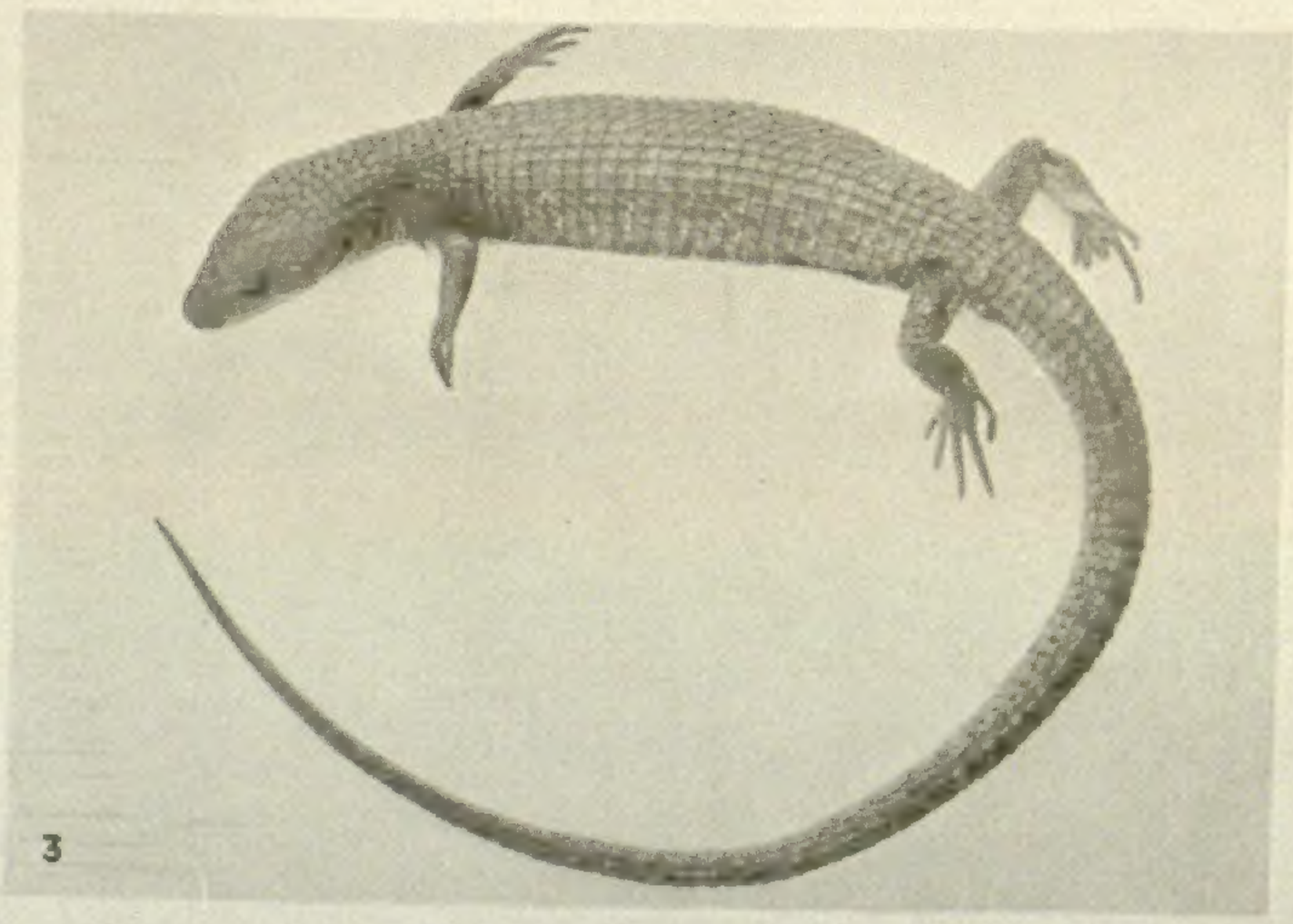


Fig. 1. *Gerrhonotus m. scincicauda* from The Dalles, Oregon. Fig 2. *G. c. shastensis* from Trinity County, California. Fig. 3. *G. c. palmeri* from General Grant National Park, California. All males.

sheltered to protect them from the cold would likewise be insulated during the warmer part of the day and their development retarded by the constantly low temperature. Delay in hatching would be a serious handicap because of the late breeding season and short growing season. It is perhaps significant in this connection that *Gerrhonotus coeruleus* usually ranges to higher altitudes and farther north than the oviparous *Sceloporus graciosus* and *Eumeces skiltonianus* which are apparently less sensitive to cold and become active at lower temperatures.

G. coeruleus seems to require more water than does *multi-carinatus*. The lizards kept in captivity were watered daily and when their cage was sprinkled, individuals of *coeruleus* became animated to the point of running about the cage and greedily lapping up the drops, while the *multi-carinatus* were more indifferent and drank sparingly.

The high percentage of these lizards having regenerated tails seems to indicate that the tail is frequently used with success as a decoy to divert the attention of an enemy. In *Gerrhonotus* as in certain other lizards, notably the Gila monster, the tail apparently functions as a reservoir for storing nourishment. Normally it is round and plump, containing a large amount of fatty tissue. In captive individuals which have been fasting, or in females which have recently given birth to young, the tail becomes shrunken and wrinkled near the base and crooked terminally, showing a decrease in diameter although the lizard itself may not be noticeably emaciated. In individuals that have had the original tail broken off near the base, the short regenerated portion is often swollen proximally and is thicker than the old tail, to compensate for its shorter length.

Oregon Alligator Lizard

Gerrhonotus multi-carinatus scincicauda

This subspecies is a characteristic inhabitant of the Garry oak belt. It is sometimes found in the Transition Life Zone, where yellow pine, black oak and madrone are the dominant plants, but I have never found it in thick coniferous forests.

The oak bushes among which it lives supply abundant food and shelter in the layers of dry, windblown leaves, often several inches in depth, which collect under them. Concealed beneath the leaves around the roots of the bushes are cracks and holes into which the lizard may escape. In times of danger it burrows rapidly into the carpet of leaves with undulatory movements of the body and tail. The short limbs play a minor part in this action. Once hidden, it silently works its way around to some hole or crack into which it escapes. When the lizard is cut off from this mode of retreat, it usually attempts

to escape by circling to the opposite side of the bush, where it emerges from the dry leaves and cautiously climbs into the concealing foliage. At such times its slow gliding movements often escape the notice of the collector who continues to search for it on the ground.

At certain times of the year these lizards do most of their foraging away from the bushes in the surrounding "needle grass" when insects are more abundant there. In the early summer when the grass is high but still green, it is swarming with young grasshoppers, which the lizard hunts during the daytime. During the hotter part of the summer when the grass has become dry, the adult grasshoppers and many other insects are found in the bushes and are hunted there by the *Gerrhonotus* which does not emerge from its shelter until late in the afternoon and does most of its feeding after sunset. I have been unable to determine how late the lizards continue to forage, but on warm nights I have heard them rustling in the leaves and have glimpsed them with the aid of a flashlight after 9 o'clock when it was almost pitch dark. On cool cloudy days they become active earlier and return to shelter before dark. On warm mornings I have usually found them to be inactive and resting in hiding places.

During cool days in September and October, before going into hibernation the lizards sometimes bask in the sun in open spots during the warmer part of the day. Young of the year remain active in the fall longer than do adults. None is to be seen from the end of October until the latter part of March. Unlike the southern subspecies, the Oregon Alligator Lizard probably hibernates well beneath the surface of the ground, since in the winter I have never found it in places such as it seeks for temporary shelter during the summer months; namely, within wood rat nests or decaying logs, or beneath loose bark or stones.

After being frightened back into a bush, if it does not escape down a hole, the lizard is quick to recover from its alarm. Often as the collector attempts to reach one with his noosing stick, the lizard is attracted by the movement, so that it begins to stalk the end of the stick and climbs up to strike at it. Several times in bushes too thick to permit my reaching one with a noose, I have succeeded in enticing the lizard out where it could be caught by hand, by jiggling the end of the stick or scraping a dry leaf with it. While hunting them I have often noticed that, although they are shy when foraging, and instantly are put on the alert by a slight rustling of dry leaves, they pay no attention to the sound of the human voice.

In capturing its prey the lizard usually glides slowly toward it, pausing at intervals to make lateral peering movements with

PLATE II.

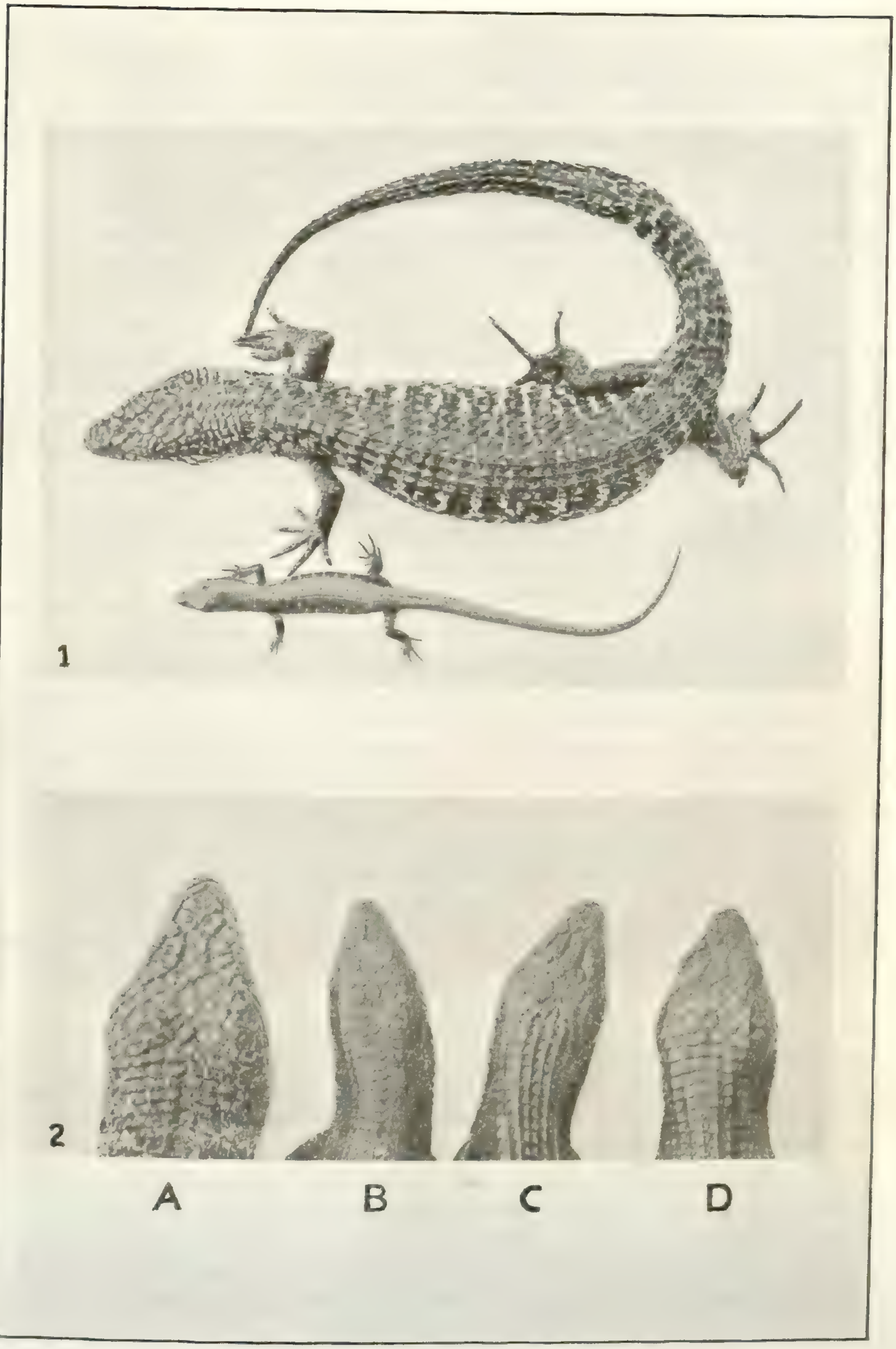


Fig. 1. *Gerrhonotus c. shastensis,* female and young from Shasta County, California. Fig. 2. (a) *G. c. shastensis;* (b) *G. c. principis;* (c) *G. c. coeruleus;* (d) *G. c. palmeri.*

the head and neck, viewing the object from different angles. When within striking distance it extends both hind legs forward along the sides of the body, braces the hind feet against the ground and then catches the desired object with a sudden forward spring which may cover several inches. If it happens to be climbing through a bush at the time the capture is made, it is saved from falling by wrapping its tail around a branch. Although they do not seem nervous or excitable in captivity, caged lizards display much less efficiency in the stalking and capture of their prey than do those foraging under natural conditions.

Stomachs of ten specimens taken at Dark Hollow, Jackson County, Oregon, during August contained 12 beetles of various sizes, a cicada, a wasp, a cutworm, a small hairy caterpillar, 20 grasshoppers, and a spider. Stomachs of four taken during July at Mill Creek, Wasco County, Oregon, contained 28 beetles (2 *Calosoma calidum*, 7 *Eleodes*, 19 undetermined), a grasshopper, and a scorpion (*Vejovis*). Stomachs of two from Spencer's Butte, Lane County, Oregon, contained 2 grasshoppers, a termite (*Reticulitermes*), and a snail; one taken 5 miles south of Ashland, Jackson County, Oregon, had eaten a beetle grub, a small beetle, a grasshopper, and a spider. One taken at Little Applegate River, Jackson County, Oregon, was feeding upon army worms.

Small skinks (*Eumeces*) and fence lizards (*Sceloporus*) were eaten by captive individuals whenever they were offered. They were usually caught by the back of the neck, crushed, and swallowed head first. On one occasion a half-grown fence lizard was chased about the cage persistently and finally was caught by the tail. As the alligator lizard began to work its jaws forward the tail parted. The larger lizard's attention was not at all diverted by the squirming tail, for although this was chewed and swallowed, it meanwhile continued to pursue the fence lizard, lunging clumsily at it and finally catching it by a hind leg. It then gradually worked its jaws forward on the body of the smaller lizard, engulfing it tail end first.

A small frog (*Rana boylii*) was placed in the cage. When it moved, one lizard stalked it and bit it on the side but released it immediately and rubbed its mouth on the ground. When the frog moved again, another lizard came and stood over it ready to seize it, but after examining it for a moment, relaxed and touched the amphibian with its tongue, then lost all interest and turned way.

A scorpion was dropped in front of a captive individual. At first the alligator lizard seemed not to notice it but, after a moment, approached, although it had not moved, stood over it

and examined it, and then seized it by the dorsal side of the abdomen. Held in this position the scorpion was unable to reach the lizard with its chelae but struck repeatedly with its sting. The first few blows hit on the scales of the temporal region and seemed to have no effect, then the sting struck the soft skin at the corner of one eye. The lizard showed signs of discomfiture and rubbed the scorpion on the ground, but continued to swallow it. For several minutes that it was watched after the scorpion had been swallowed, it kept the eye tightly closed. On the following day it was examined and found to be normal.

When a three-fourths grown house mouse was placed in a cage with several of these lizards of various sizes, a close connection between defense reactions and feeding was shown. The larger lizards at once began stalking the mouse but were hesitant in striking when they reached favorable positions. One lizard, which was less than half grown and which could not possibly have swallowed the mouse, followed it and struck at it repeatedly. Another half grown individual made no attempt at pursuit but assumed a threatening attitude, puffed up its body, opened its mouth, and then jumped at the animal whenever it came near. Twice this lizard caught the mouse in its jaws and rolled rapidly over and over, then released it and ran to the opposite end of the cage. The second time this happened, the mouse was seized by the back of the neck and was so injured when it was dashed against the ground that it died a moment later.

Later I divided the body of the mouse and dangled part of it in front of the largest lizard. The latter hissed threateningly, jumped at it several times, and finally caught and swallowed it. A part of the mouse was left in the cage and several hours afterward one of the lizards was found devouring it.

On one occasion, during a morning's collecting, reptiles of several different kinds including Oregon Alligator Lizards were placed together in a bag. When they were removed, a large alligator lizard was in the act of swallowing an eight inch yellow-bellied racer (*Coluber constrictor mormon*) and only the posterior third of the snake's body protruded from its mouth. Probably the lizard had first bitten the snake in self defense and not with the intention of devouring it. Captive individuals can be fed by hand and, if they are hungry, they will voluntarily swallow insects or pieces of raw meat placed between their jaws when they attempt to bite. In the wild, a large individual might form the habit of preying upon small mammals or birds by repeated experiences of overpowering such prey which it had first attacked as a defensive gesture.

The sight of one lizard feeding seems to stimulate others to activity, but apparently one lizard does not profit by seeing another deterred when it attacks some offensive tasting insect.

When an insect which was being stalked by one lizard was caught and eaten by another individual, the unsuccessful hunter often followed the other and bit at its jaws after the insect had disappeared. Sometimes it would shift its attention to the other lizard's side, and after examining it for a moment as if to pick out a vulnerable spot, would bite viciously, sometimes repeating this two or three times. During such a performance there are unmistakable signs of anger, twitching of the tail, rolling of the eyes, and puffing up of the body. I have noticed this behavior many times in both young and adult *Gerrhonotus*. Apparently, it involves not merely an attempt to retrieve the lost morsel of food but also a desire, as it were, to "get even".

Newly captured alligator lizards always attempt to bite, while at the same time they writhe and twist, often with an audible creaking of the stiff bony skin. At such times the contents of the bladder are ejected and feces are voided, so that the lizard in its writhings besmears its own body and that of its captor. The excreta have a sharp, nauseating odor which would probably be so distasteful to a captor that the release of the lizard would often be effected.

In one instance a half grown individual when caught seized its own hind foot in its jaws. For twenty minutes that it was carried on the palm of the collector's hand it remained twisted in an apparently uncomfortable position, retaining its hold. When it was tossed into an irrigation ditch, it performed violent contortions in the water for several seconds, then it gave up its hold and swam quickly to the bank.

The possible protective value of such behavior is suggested by the observation of Compton (1933) on an alligator lizard which held its tail in its mouth encircling a branch, and thereby prevented a garter snake from swallowing it.

The only published observations concerning the oviparous habits of this species are those of Gander (1931: 14) made on an individual of the southern subspecies, *webbii*. During the latter part of July, 1932, in the Rogue River Valley in southern Oregon, I made efforts to secure females in order to obtain data on the breeding habits. Although many adult males and immature individuals were taken, no adult females were seen. It seemed evident that they were not active at this time. The eggs are probably deposited deep underground in rodent burrows such as those of *Citellus* and *Thomomys*. They are never found in such places as the lizards themselves often occupy during the summer months (within rotting logs and stumps, or beneath strips of bark or stones) where the embryos would

probably perish from lack of moisture. The female would probably be unable to dig her own burrow for the eggs because of her feebly developed legs.

In 1933, in the Rogue River Valley, mating pairs were found on May 31, June 4, June 8, and June 12, respectively. Possibly the breeding season was delayed because of the late spring. During May, 1931, two mating pairs were seen, and in 1934 mating pairs were seen on May 14, and May 17.

Although the following observations on the breeding habits of this form were made before this study was begun and no notes were taken at that time, they are perhaps of sufficient interest to record here in so far as they can be remembered. During June, 1929, a large female was taken near Medford (see pl. 3, fig. 1) and was kept in a spacious outdoor cage. She was fed regularly with grasshoppers and other insects. After several weeks her body had become much distended with eggs. A box turtle (*Terrapene ornata*), which also was kept in the cage, had made a burrow in a sand pile and in this the lizard spent most of the time, coiled in a small side branch about a foot beneath the surface of the ground and two feet or more in from the entrance. Thirteen eggs were deposited in the burrow during the first week of August. They were arranged close together and in a single layer, partly covered with sand. They were white, and oval in shape with tough leathery shells, and resembled the eggs of *Sceloporus* in appearance except for their larger size. They contained embryos which were still in an early stage of development, occupied less space than the yolk, and were not yet recognizable as lizards.

Over a number of years that I have been familiar with alligator lizards in Rogue River Valley I have each year first noticed newly hatched young in September, therefore a month or more evidently is necessary for the embryos to complete their development after the eggs are laid.

Red-backed Alligator Lizard

Gerrhonotus multi-carinatus multi-carinatus

In different parts of its range this form occupies a variety of habitats. It inhabits thickets of underbrush in groves of trees of the bottomlands along rivers in the Sacramento Valley (pl. 3, fig. 2), the digger pine and yellow pine belts in the northern Sierra foothills, oak forests, chaparral, and, in the coastal area, sand dunes and rocky, treeless hills. It occurs mainly in the Upper Sonoran Zone but is found also in both the Transition and the Lower Sonoran.

In the warmer part of the range of this subspecies hibernation seems to be incomplete, but farther north and at high altitudes it probably lasts for several months. Grinnell, Dixon,

and Linsdale (1930: 147) record two juveniles found on December 29, 1927, on the surface of the ground under boards near Red Bluff. Four (Mus. Vert. Zool. nos. 4266-4269) were collected on December 16, 1912, at Napa. On January 21, 1932, in Strawberry Cañon near Berkeley I found an individual crawling through thick grass at the edge of a log on a warm afternoon. On February 12, 1932, at Daly City near San Francisco, I found individuals on the surface of the ground beneath rocks in a semi-active condition. A series in the California Academy of Sciences collection was taken on December 30, 1906, at Carmel, Monterey County.

Stomach contents of six adults taken at Daly City on May 1, 1932, were analyzed with results as follows: 1 butterfly, 2 cutworms, 1 mosquito, 3 Jerusalem crickets (*Stenopelmatus*), 2 ants, 6 small beetles (less than 10 mm. in length), 2 large beetles (more than 10 mm. in length), 1 bug, 2 spiders, one with its egg sac, fragments of white eggshell .2 mm. in thickness (*Zenaidura*?).

The stomach of a large specimen taken in tall grass near Lagunitas, Marin County, May 8, 1932, contained a single large cutworm (noctuid?).

Stomachs of two specimens taken on June 29, 1932, 21 miles north of Redding, Shasta County, contained insect remains as follows: 1 noctuid larva (length 21 mm.), 17 small beetles of several different species (average length 7 mm.), 1 beetle larva.

On one occasion a number of large beetles of a kind having an offensive secretion (*Scaphinotus*) were offered to captive lizards of this subspecies. The beetles were attacked at once and several were killed and eaten, but in all cases the lizards showed strong distaste for them and rubbed their mouths against the ground after having bitten them. Usually the beetles were released as soon as they gave off their offensive secretion. One was kept in the cage for six weeks and during this time was not harmed by the lizards. During the first few days the sight of this beetle walking across the cage would often stimulate a *Gerrhonotus* to pursue it, but the lizard after overtaking it would always turn away without striking. Evidently the feeding reaction was inhibited by memory of a previous disagreeable experience invoked by a closer view of the beetle. Later the lizards grew accustomed to the beetle's presence and ignored it altogether.

When a half-grown house mouse (*Mus musculus*) was placed in the cage, the lizards at once became attentive. Several stalked it simultaneously and one caught it across the head and crushed its skull, killing it almost instantly. The lizard swallowed the mouse head first having much less difficulty in engulfing its soft body than is usually experienced by individuals attempting

to swallow insects of the same size. The prey was seemingly drawn into the stomach as if by suction and by contractile movements of the neck muscles rather than by action of the jaws. Although there were several San Francisco Alligator Lizards in the cage larger than the Red-backed Alligator Lizard which had killed and eaten the mouse, none of them had made any attempt to capture it.

On June 29, 1932, I collected specimens of this lizard along a small creek in the digger pine belt north of Redding in Shasta County. All that were seen were among dry leaves beneath thick bushes of wild grape and poison oak along the banks of the stream. The lizards were foraging under the bushes in the middle of the afternoon although the temperature was high, over 90° F. They were wary and quick in their movements and were much more difficult to approach than were the Shasta Alligator Lizards which had been collected on the day before. After two attempts to noose a large individual had failed, it suddenly ran down the bank into the water and hid beneath a rock, entirely submerged except for the end of its tail. For eight and a half minutes it remained motionless. At the end of this time it shifted its position and cautiously thrust its head above the surface under a floating leaf. It did not move from this new position until it was captured ten minutes after it had first entered the water. It seemed unlikely that in this case the lizard intelligently or even instinctively sought the water as an avenue of escape. More probably its action was accidental. Being at a disadvantage and unable to move rapidly in the water, it had made the best of the situation by hiding.

On October 1, 1932, an individual was found in Strawberry Cañon, Alameda County, stretched in the road sunning itself in the late afternoon. Seeing the lizard from a distance I approached cautiously, taking care to come from behind it on the lower side of the road. As I approached to within a few feet it seemed to be watching me and following my movements with a slow, almost imperceptible turning of its head. For five minutes that it was watched it made no other movements. It was poked with the end of a stick and shoved a short distance but its body was limp. Convinced that it was in some way injured, I reached down to pick it up. As it was being lifted from the ground it darted forward across the road and up a vertical five-foot bank with such suddenness and speed that it nearly escaped. When caught it struggled vigorously and attempted to bite.

Seldom found more than a few feet from shelter, alligator lizards are perhaps too slow to outstrip an enemy when they are by chance caught in the open. "Playing possum" until a

favorable moment arrives for a dash to safety, may often save the lizard's life.

The individual involved in the foregoing observations was on the following day made the subject of an experiment with captive magpies (*Pica pica hudsonia*). When it was placed in the cage with the birds, it immediately assumed a defensive attitude, standing high off the ground with the body tilted toward the nearest bird. The head was turned sideways to the body and lowered, with jaws gaping, protecting the neck on the side from which attack was expected. The body was slightly bent laterally, with the concavity on the side which the lizard was facing. The tail was looped in a half circle in front of the body with the result that the magpie pecked at it first after a cautious approach. The *Gerrhonotus* sprang at the bird with a sudden straightening of its body. The bird dodged and jumped back. When the magpie was eight or ten feet away, the lizard seemed to lose track of its position except when it was moving. Several times when a bird came near, the *Gerrhonotus* charged straight toward it for a foot or more, driving it back.

All three magpies in the cage became highly excited and hopped around the lizard, each in turn closing in to deliver a peck as it turned in the opposite direction. The lizard showed inability to watch more than one assailant at a time, or to shift attention rapidly from one to another. During the encounter the lizard's tail was broken. At the instant the tail parted none of the birds was touching it, but undoubtedly it had been injured by them as many blows had landed upon it. Up to this time the lizard had made no attempt to escape but had for the most part taken the offensive. It now made a short run to the nearest shelter, a dish in the cage beneath which it hid. At this instant the attention of all three birds was focused upon the squirming tail whose lively movements were in contrast to the previous inactivity of the lizard itself. Evidently they failed to distinguish between the tail and the lizard. No further search was made for the reptile after one of the birds had "overpowered" and eaten the tail. Many other individuals which were placed in the magpie cage at different times showed similar defense reactions.

When a large king snake (*Lampropeltis getulus boylii*) was placed in a cage with the lizards referred to above, the reaction was strikingly different. The lizards would crouch motionless until the body of the snake brushed against them. They would then rush frantically along the sides of the cage trying to escape through the screen, and would make no attempt to bite the snake or to drive it off as they had the birds. Half an hour

after the snake was removed the lizards were restless and seemingly had not recovered from their fright, as most of them were climbing about the top of the cage.

Two half-grown specimens in the Stanford University collection, both having head and body lengths of about 70 mm., were taken from the stomach of a racer (*Coluber*), according to the label enclosed with them. Another from Chalk Peak, Monterey County (Mus. Vert Zool., no. 7236) having a head and body length of 82 mm. was taken from the stomach of a California racer (*Masticophis lateralis*).

Miller (1931: 200) lists *Gerrhonotus scincicauda* (probably referring to the present form) as one of the reptiles used for food by the shrike, *Lanius ludovicianus*.

On May 1, 1932, at Daly City, I found two mating pairs of Red-backed Alligator Lizards. Individuals of this form were unusually active and were moving about in the open on this date. Many were seen during the day and they were much more in evidence than San Francisco Alligator Lizards which on other occasions have been found to be the more abundant in this locality. The majority of those seen were adult males. Evidently the breeding season is limited to a short period at this time of year.

Neither of the pairs was copulating when they were found, at about noon. In each case the male held the head of the female across the temporal and occipital region of one side, in his jaws. (See pl. 4, fig 2.) When first seen the lizards of both pairs were walking about in short grass, stopping at intervals. Later they moved beneath small bushes where they became quieter.

A large adult male, which was caught during the course of the afternoon, was released and started in the direction of one of the mating pairs, from a distance of several yards. The pair was near a hole at the base of an outcropping of rock and the lizard which was liberated made for this hole. When first set free, it made a short run, then progressed more slowly, gliding through the grass with occasional pauses. It did not see the other lizards, but as it approached, the mating male showed signs of anger by inflating his body, rolling his eyes, and twitching his tail. When the intruding male had come within a few inches, the other suddenly released the female, ran at him, seized him by the side, and bit viciously. The attacked male retaliated and for a moment the two rolled about, writhing and twisting as they bit one another. They separated, and the male which had made the attack ran back into the mouth of the hole down which the female had meanwhile disappeared. The other seemed bewildered and ran about aim-

PLATE III.

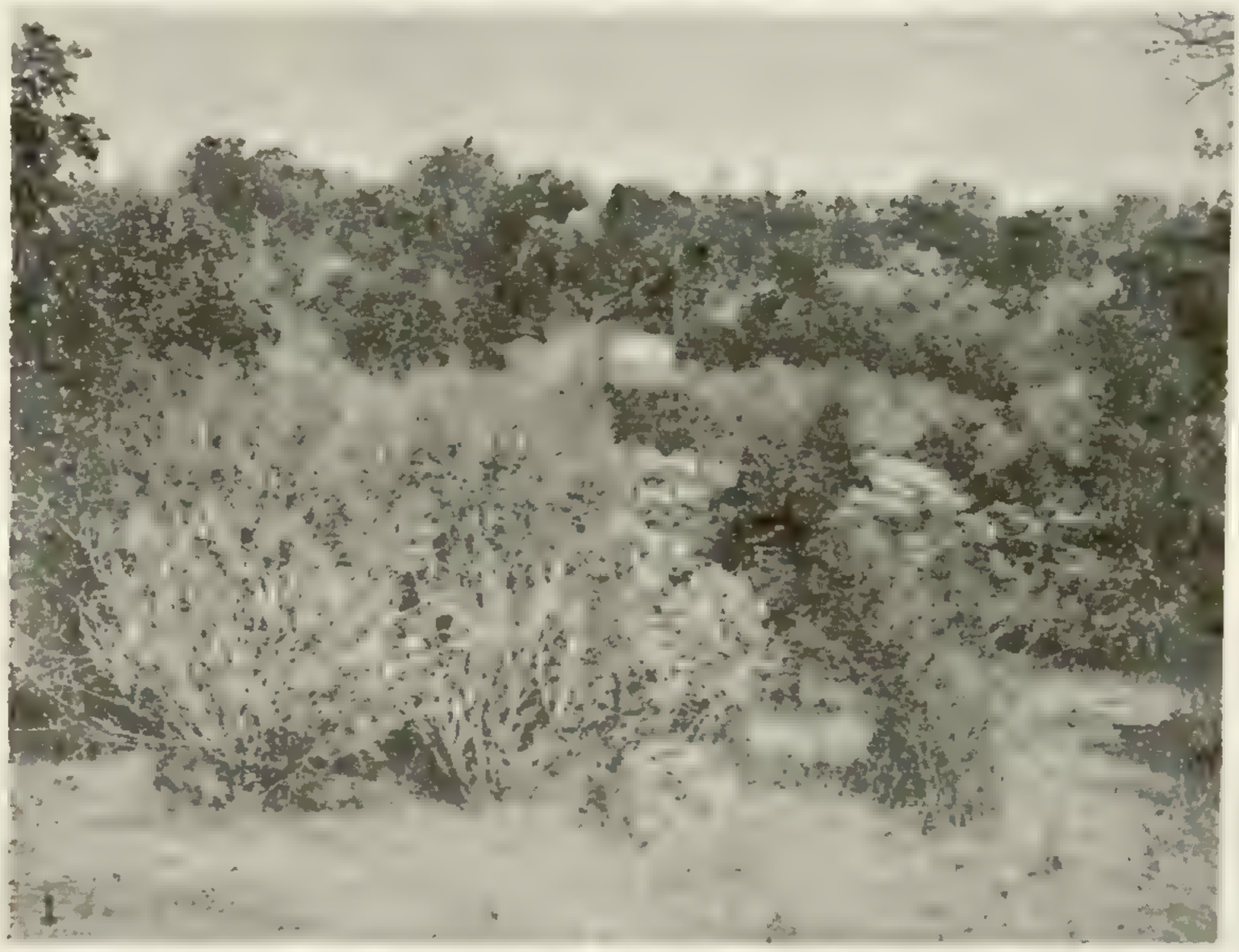


Fig. 1. Habitat of *Gerrhonotus m. scincicauda* in Jackson County, Oregon.
Fig. 2. Habitat of *G. m. multi-carinatus* in Butte County, California.
Fig. 3. Habitat of *G. c. shastensis* in Jackson County, Oregon.

lessly for a moment, then made for the nearest shelter, which happened to be the same hole. As he reached the entrance, the first male ran out and again attacked him. In the ensuing struggle both were captured by the observer. The female did not reappear.

The second pair was maneuvered into a bag and brought back to Berkeley without separating them. Copulation took place at intervals on the following day. Twenty-six hours and possibly more were required for the completion of mating. The process was undoubtedly much retarded by the frequent disturbances resulting from moving, observing, and photographing the lizards.

Probably an individual *Gerrhonotus* does not mate more than once a year. Captive males which had mated showed no further interest in females which were kept with them. A high mortality during the breeding season might be expected to result from the attacks of predatory animals because of the long time required for mating and the indifference of the lizards to their surroundings.

Females containing embryos are found only during the months of May, June, and July, and the developing ova gradually increase in size during this time. The number of eggs laid is probably dependent on the size, age, and condition of the female. Females containing ova have been examined as shown in the accompanying table.

Table showing size and number of eggs in breeding females of G. m. multi-carinatus examined

(Measurements in millimeters)

Locality, in California	Date	No. of eggs	Av. size of eggs in mm.	Head & body lgh. of female in mm.
Lyonsville, 3500 ft., Tehama Co.	Apr. 26, 1928	16	2.5 x 2.5	129
Daly City, San Mateo Co.	May 1, 1932	6	9 x 8	112
Mt. Diablo, Contra Costa Co.	May 17, 1921	12	8 x 6.5	114
Nortonville Mine, Contra Costa Co.	May 21, 1931	11	14 x 9	118
Beegum, 1250 ft., Tehama Co.	May 23, 1926	13	13 x 9	132
Manton, 2300 ft., Tehama Co.	May 30, 1926	14	9 x 8	123
Berkeley, Alameda Co.	June 2, 1915	11	4 x 4	123
Dale's Ranch, Tehama Co.	June 2, 1924	11	9 x 9	124
Manton, 2300 ft., Tehama Co.	June 4, 1926	17	10 x 10	140
Mill Creek, Tehama Co.	June 14, 1912	9	14 x 9	135
Rumsey, Yolo Co.	June 29, 1912	12	16 x 10	144
Gilroy, Santa Clara Co.	June ...., 1910	10	16 x 9.5	115
Vacaville, Solano Co.	July 7, 1912	9	15 x 9	136

San Diego Alligator Lizard

Gerrhonotus multi-carinatus webbii

I have not myself observed *webbii* in the field; however, good accounts of its habits have been given by other observers. It frequently climbs through vines and bushes in foraging (Grinnell and Grinnell, 1907: 30), or to escape pursuit (Atsatt, 1913: 38). Its relatively long and slender tail may be an adaptation in this direction. Because of its larger size it is probably more often predatory on small vertebrates than are other forms. Grinnell and Grinnell (loc. cit.) tell of one which seized and made off with a cactus wren after the bird had been shot. Gander (1931: 14) described the feeding of a captive individual, which ate fence lizards and a mouse as well as insects which were offered, attempted to devour a pigeon egg placed in its cage, and attacked a tree frog but was repulsed by the latter's offensive secretion.

The alimentary canal of one specimen which was examined contained only a trace of organic matter which could have been swallowed as food (beetle fragments and hair of a small mammal) but was crammed with a fine abrasive gravel. Numerous parasitic nematode worms were noted in the stomach and intestine. Possibly the lizard had eaten the gravel as a means of ridding itself of these worms.

Grinnell (1908: 168) records finding a specimen 10⅜ inches in length in the stomach of a 26 inch rattlesnake collected in Santa Ana Cañon, San Bernardino Mountains on June 20, 1907.

Linsdale (1932: 370) writing of this subspecies in Lower California stated: "That red-tailed hawks may sometimes capture and eat this kind of lizard is shown by the experience of a collector at La Grulla [in Sierra San Pedro Mártir] on May 22, 1925. A *Gerrhonotus* was dropped from the talons of one of these hawks when it was shot."

On May 23, 1933, Mr. James O. Stevenson collected a mating pair of alligator lizards at Sawpit Cañon, 4700 feet, near Cedar Pines Park Post Office, San Bernardino County, California. Gander (1931: 14) wrote that the alligator lizard taken on June 20, 1930, and kept by him laid 15 eggs on July 17. Possibly the eggs are sometimes laid in the latter part of June. Females having developing ova have been taken as shown in the accompanying table.

Table showing size and number of eggs in breeding females of G. multi-carinatus webbii examined

No.—(Mus. Vert. Zool.)	Locality, in California	Date	No. of eggs	Av. size of eggs in mm.	Head & body lgh. of female in mm.
2863	Bodfish, 2400 ft., Kern Co.	June 19, 1911	12	11 x 11	145
4265	Tujunga, Los Angeles Co.	June 19, 1909	15	14 x 8	120
8007	Big Rock Creek, 4300 ft., Los Angeles Co.	June 22, 1920	15	14 x 8	139
8008	Big Rock Creek, 4300 ft., Los Angeles Co.	June 22, 1920	15	14 x 8	133
269	Schains, 4300 ft., Riverside Co.	June 27, 1908	13	13 x 8	127
2868	Isabella, 2500 ft., Kern Co.	June 29, 1911	9	16 x 10	137
2870	Fay Creek, 4100 ft., Kern Co.	July 14, 1911	8	18 x 10	134

There is probably some variation in the size of the young at the time of hatching so that those of the same size are not necessarily of the same age. Young of the year have been taken as follows:

No.—(Mus. Vert. Zool.)	Locality, in California	Date	Head and body length in mm.
12859	Slover Mountain, San Bernardino Co.	July 30, 1931	35.5
501	Valle Vista, San Jacinto Valley, Riverside Co.	Sept. 1, 1908	35.5
899	Pasadena, Los Angeles Co.	Sept. 29, 1904	33.5

Northern Alligator Lizard

Gerrhonotus coeruleus principis

Apparently it is characteristic of the Northern Alligator Lizard to occur in concentrated colonies. Perhaps this habit is correlated with the lizard's relatively small size and with the abundance of shelter and insect food in the dense vegetation of its habitat, and this most favorable type of habitat is interrupted.

On October 20, 1929, I observed lizards of this race at Siltcoos Lake, a few miles from the coast in Lane County, Oregon. The weather was mild and had been so for several days. The lizards were active during the middle of the day. They were abundant along the shore of the lake, at the edge of thick woods surrounding it. They were sunning themselves or crawling about through the bushes, logs and debris just above high water line. At Newport, Lincoln County, Oregon, several individuals were found on the beach under loose slabs of rock at the base of a cliff.

On July 21, 1932, I found *principis* to be abundant near Bandon, Coos County, Oregon. Most of those found were

under logs in an open glade in the forest. Port Orford cedar and Douglas fir were dominant, with a heavy undergrowth of blackberry and tall ferns, and, in the open, dry grass a foot or more in height. The temperature was high during the middle of the morning when the lizards were collected, but they were apparently not feeding at this time of day. All but one were found under logs. Although they were not especially active or quick in their movements, most of those that were discovered escaped into thick cover. When the tail of one was broken as the animal was captured, the disconnected member performed such lively movements that for a moment both observers who were present mistook it for a fluttering moth or butterfly. Most of the logs which offered suitable hiding places for the lizards were too large to be moved and consequently it is probable that only a small fraction of the lizards actually present were seen, yet in some places several were seen within a few square yards. The stomachs of seven specimens taken at this locality contained 10 small beetles, 1 crane fly, 1 noctuid moth, and 1 snail.

Females containing developing ova were taken as follows:

No.—(Mus. Vert. Zool.)	Locality	Date	No. of eggs	Av. size of eggs in mm.	Head & body lgh. of female in mm.
15105	Bandon, Coos Co., Oregon	July 21, 1932	3	17 x 15	80
15106	Hunter Creek, Curry Co., Oregon	July 22, 1932	5	10 x 7	86

Shasta Alligator Lizard

Gerrhonotus coeruleus shastensis

This subspecies ranges from sea level up to at least 6800 feet and from the sea-coast more than 200 miles inland. Its subjection to a wide range of environmental conditions is reflected in its variability. It usually chooses for a habitat a well drained situation where there is abundance of decaying wood on the ground, preferably where bushes, trees, and open grassy places offer a variety of forage within a small area. Often it is abundant along creeks.

On June 29, 1932, I collected specimens at Grass Valley Creek, Trinity County, California. The weather was warm and the lizards were active but during the middle of the day they kept in the shade beneath the thick growth along the creek, consisting of maple, alder, ash, yew, Douglas fir, blackberry, willow and tall ferns. Many lizards were found several feet above the ground crawling along nearly horizontal branches or logs. One individual first seen on the ground attempted to

escape by climbing up the vertical trunk of an ash tree eight inches in diameter, with bark only sufficiently rough to offer a good claw hold. With two or three pauses the lizard climbed straight up to a height of ten feet, then turned and started back down. When it was touched with a stick by the observer, it dropped to the ground. In several hours, the same day, over twenty lizards were taken, most of them adult males. In this locality they seemed to be closely restricted to the vicinity of the creek. An hour's search on the south facing slope north of the creek, in open woods of black oak and yellow pine, failed to disclose any specimens. A single *G. multi-carinatus scincicauda* was found foraging near the creek and apparently occupying the same niche as the more abundant Shasta Alligator Lizards.

On June 27, 1932, I collected a number of specimens, including the type, near Burney, Shasta County. Alligator lizards seemed to be quite limited in habitat and were found only in, or at the edge of, a small meadow, either moving through the short grass or hiding under scattered logs and boards. When found, they were easily caught by hand and apparently had no system of escape. The grass was high enough to impede their progress without offering concealment and the ground was hard and packed, with no cracks or holes. The lizards were seemingly at the mercy of any enemy which could turn over or get beneath the small pieces of wood under which they concealed themselves, or catch them in the open. Among possible enemies may be mentioned the rubber snake (*Charina bottae*) which was also found in the meadow. No *Gerrhonotus* could be found in the surrounding open woods of yellow pine, although conditions there seemed favorable, judging from my experience in collecting the lizards elsewhere.

A racer (*Coluber constrictor mormon*) taken near Kuntz, on Mad River, Trinity County, on June 12, 1934, was found to have eaten one of these lizards.

On March 31, 1932, I spent most of the day hunting *Gerrhonotus* at Lyonsville, Tehama County. The day was warm but there were still patches of snow in sheltered spots and the ground was damp everywhere. *Sceloporus* and *Eumeces* were already out abundantly, but apparently *Gerrhonotus* was not yet fully active, as only two were found.

On July 11, 1932, specimens were collected near Lake of the Woods, Klamath County, Oregon, at an altitude of slightly over 5000 feet, in typical Canadian Life Zone, lodgepole pine and *Ceanothus velutinus* being the dominant plants. There had been

a light frost on the night preceding, and during the morning hail and showers alternated with brief sunny periods. In spite of the cold weather, several alligator lizards were seen foraging and others were found under logs. They could be found only on an open south facing slope. In this locality, where there is frost every month in the year, garter snakes are the only other reptiles found.

The stomachs of 17 specimens taken at Grass Valley Creek, Trinity County, on July 29, 1932, contained 217 invertebrates which were identified as follows: *Lepidoptera*—63.6% mostly Noctuidae, a few Geometridae mostly larvae averaging 20 mm. in length; *Coleoptera*—17.5%; Cerambycidae (*Rosalia*), Circulionidae (*Pissodes*), Carabidae (*Scaphinotus*), Bupestridae (*Trachykele, Chrysophana,* probably others); *Diptera*—4.6% Tipulidae (*Holorusia* both larvae and adults), Asilidae (*Asilus*), Culicidae, Calliphoridae; *Orthoptera*—4.1% Tettigoniidae (*Stenopelmatus, Ceuthophilus*); *Hymenoptera*—1.8% Vespidae (*Vespula*), Ichneumonidae (*Megarhyssa*), bee (unidentified); *Hemiptera*—1.8% Pentatomidae; spiders—3.2%; millipede—.9%; snails—1.4%.

Stomachs of five specimens taken near Burney, Shasta County, on June 27, 1932, contained 14 noctuid moth larvae, 23 beetles, 1 grasshopper, 2 large spiders (length 17 mm.).

Eleven specimens taken on July 4, 1932, 10 miles east of Ashland, Jackson County, Oregon, at 4000 feet had eaten 21 grasshoppers, 14 small beetles (under 10 mm.), 1 grub, 1 noctuid moth larva (length 18 mm.), and 1 spider (length 7 mm.).

Stomachs of four specimens taken on July 17, 1932, at the head of Lost Creek, Jackson County, Oregon, contained 2 grasshoppers, 5 small beetles, 1 small hairy caterpillar, 2 grubs, and 1 spider.

Excreta of eight individuals taken 10 miles east of Ashland, Jackson County, Oregon, on September 7, 1931, were made up mainly of grasshopper remains.

Thirteen specimens taken on July 11, at Rainbow Creek, Klamath County, Oregon, had the following material in their stomachs: 21 grasshoppers, 3 small beetles, 1 snail, traces of mammalian hair, feather of a small passerine bird, a large patch of sloughed skin from the same lizard's own tail. The lizard having the feather in its stomach was far too small to have eaten a bird. Either it had taken the feather accidentally with its food or it had been on the defensive when it had bitten the feather from some bird, and then had swallowed it.

Table of breeding females collected during summer of 1932 showing size and number of developing ova

No.—(Mus. Vert. Zool.)	Locality	Date	No. of eggs	Av. size of eggs in mm.	Head & body lgh. of female in mm.
15040	Burney, Shasta Co., Calif.	June 27	10	11 x 8	120
15048	Burney, Shasta Co., Calif.	June 27	7	12 x 7.5	104
15057	Grass Valley Creek, Trinity Co., Calif.	June 28	6	12.5 x 7.5	115
15061	Grass Valley Creek, Trinity Co., Calif.	June 28	9	6 x 6	113
15065	Grass Valley Creek, Trinity Co., Calif.	June 28	6	14 x 9	104
15069	Grass Valley Creek, Trinity Co., Calif.	June 28	7	13 x 9	99
15076	10 mi. E. Ashland, Jackson Co., Ore.	July 4	3	15 x 9	93.5
15077	10 mi. E. Ashland, Jackson Co., Ore.	July 4	7	13 x 9	107
15078	10 mi. E. Ashland, Jackson Co., Ore.	July 4	8	13 x 9	108
15079	10 mi. E. Ashland, Jackson Co., Ore.	July 4	6	12 x 9	103
15115	Rainbow Creek, 5100 ft., Klamath Co., Ore.	July 11	2	15 x 8	80
15122	Rainbow Creek, 5100 ft., Klamath Co., Ore.	Aug. ?	5	11 x 9	99
15089	Wagner Gap, 4800 ft., Jackson Co., Ore.	Aug. 10	5	16 x 12	105
15090	Wagner Gap, 4800 ft., Jackson Co., Ore.	Aug. 10	7	16 x 12	110
15091	Wagner Gap, 4800 ft., Jackson Co., Ore.	Aug. 10	6	16 x 12	100

Table showing size and number of young in broods of G. c. shastensis born in captivity

Locality of capture	No. of young	Date of birth	Av. length of young, snout to tip of tail in mm.	Head & body lgh. of female in mm.
Grass Valley Creek, 2000 ft., Trinity County California	7	Sept. 7, 1932	73	105
Burney, 3000 ft., Shasta County, California	7	Sept. 12, 1932	85	110
10 miles east of Ashland at 4000 ft., Jackson Co., Oregon	6	Sept. 14, 1931	85	105

Observations on the birth of young were made on September 7, 1932, when, at 8:30 a. m., three newly born young were found in the box with a female from Grass Valley Creek, Trinity County. During the remainder of the morning the female was kept under observation. She rested motionless until 9:50 a. m. when she elevated her hind legs so that the feet were clear of the ground. At 10:00 a. m. the legs were farther elevated so that the thighs were pointing upward at 30° from the horizontal. The knees were flexed at right angles and the soles of the feet were turned upward. From time to time there were slight twitching movements of the lizard's sides. At

10:10 a. m. a young one (thus the fourth of the brood) was suddenly ejected. It was enclosed in a membranous sac and coiled with the legs extending backwards along the sides and the head and tail folded on the body. A piece of egg yolk about 4 mm. in diameter was enclosed with it. At 10:12½ a. m. the young made a slight movement. The female paid no attention to it but became active and crawled to a corner of the box. Here she again elevated her hind legs and after a few movements of her sides ejected another young, at 10:23 a. m.

The first young one was still lying coiled and motionless. At 10:27 a. m. the second young one made feeble movements which gradually became more pronounced, and at 10:53 a. m. it tore itself free from the enclosing membrane and ran clumsily across the end of the box. In running, its movements were stiff and jerky, resembling those of a salamander. At 11 a. m. the female touched it with her tongue as she passed. Thus stimulated, it ran to another corner of the box. A few moments later the female again came face to face with it as she moved about the box. This young lizard was now fully active and, as the female approached, it gave a characteristic fear reaction (backing away and nervously thrashing the tail), then turned and darted away to the far end of the box. The first young one did not make vigorous attempts to escape from the membrane enclosing it until about an hour after the time of parturition. It then experienced difficulty, since the membrane had dried and adhered to it. An hour and a half had passed before it became fully active and could open its eyes and protrude its tongue. At 11:55 another young one was born. The female gave birth to the seventh and last of the brood at 1:30 p. m. The young were active and restless. They apparently underwent a partial molt immediately after birth, as they were seen to rub off small patches of skin.

Young kept in captivity fed poorly and showed no perceptible growth even when they were kept for several months.

Throughout its range, *shastensis* has a dark and a light extreme of coloration often existing side by side (pl. 1, fig. 2). This difference apparently is not correlated with sex. The dark extreme is the more common and the majority of individuals are more or less intermediate. In series from almost any locality individuals may be picked showing differences which might well be of specific value, were they constant in geographically separated races.

The optimum habitat conditions seem to be in a borderline environment, hence one that is shifting and transitory locally. Assuming that the color pattern is not purely incidental but is

PLATE IV.

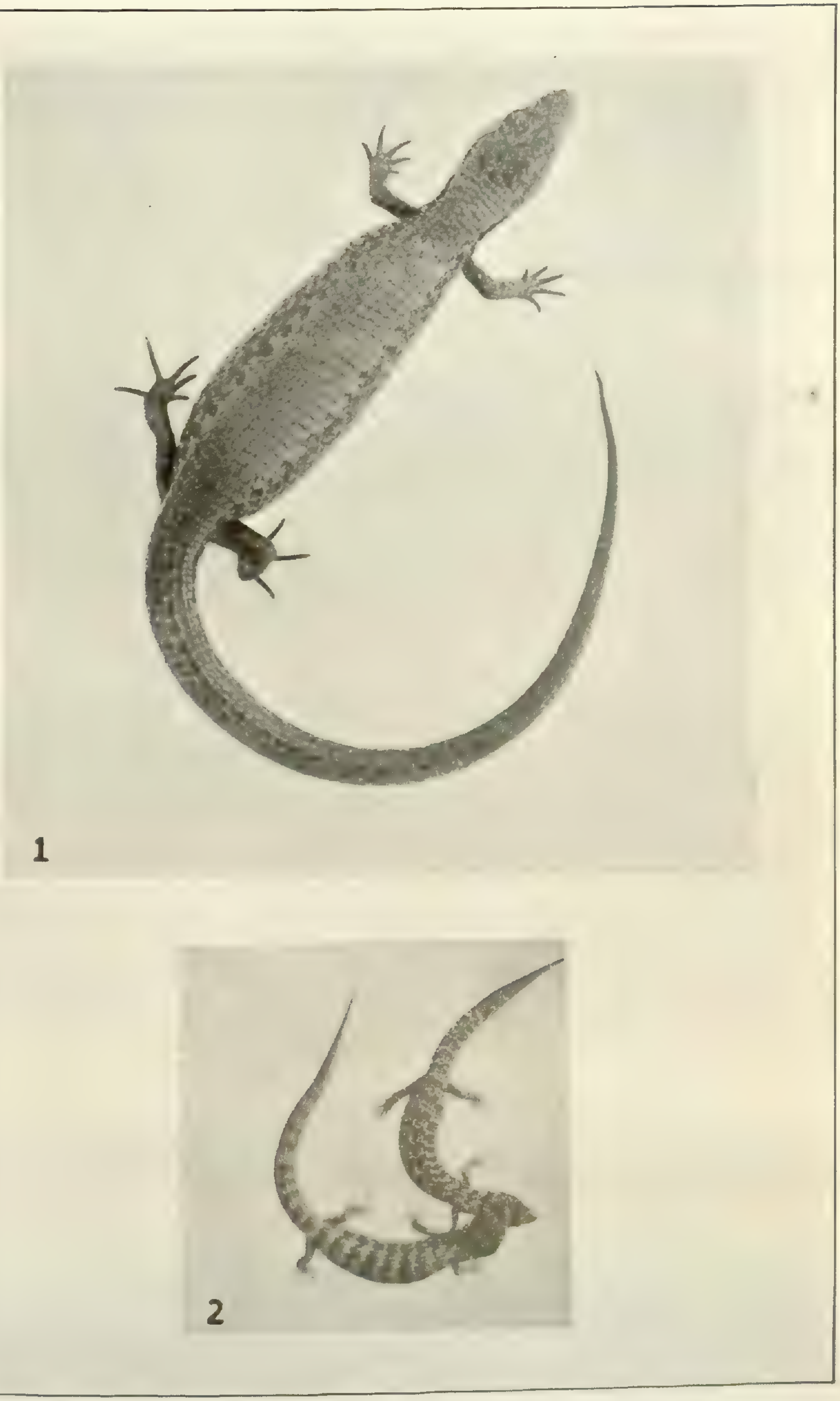


Fig. 1. Adult female of *Gerrhonotus c. principis.* Fig. 2. Mating pair of *G. m. multi-carinatus.*

of some functional value to the lizard, it seems probable that these unstable habitat conditions would allow for individual variation and prevent the evolving of any fixed type. Natural selection would perhaps favor first one extreme and then the other as local conditions changed.

In southern Oregon where I have seen numerous individuals of this form in the field, I am convinced that there is partial segregation of the dark and light phases in response to local conditions such as exist on the Wagner-Applegate divide in the Siskiyou Mountains. On the north, or Wagner Creek side, the mountains rise from the valley floor slightly below 2000 feet altitude to a height of 5000 feet. This north slope is covered with a dense growth of Douglas fir, madrone, black oak, and yew, which near the crest of the ridge grades into an open forest of yellow pine. The yellow pine belt gives way in turn to still more open country where mountain mahogany is the only tree, growing in low chaparral-like thickets with intervening open spaces. The higher parts of the south facing slopes are dry, rocky and treeless, with scattered clumps of sage.

Gerrhonotus is rare on the heavily timbered north slope but occasionally is found clear to the lower border. All that I have seen in this environment were heavily pigmented. Seeing the animal in its natural environment the observer is impressed by the effectiveness of its pattern in concealing it on the humus-filled ground. In the yellow pine belt, the lizards are much more abundant, but only an occasional individual is heavily pigmented. In most individuals from this habitat the dorsal black spots are small and well separated, so that the yellow-brown ground color predominates. The lizards are found concentrated in colonies about decaying pine logs and stumps. At such spots the ground is littered with slabs of loose bark beneath which the lizards find abundant food and shelter. The ground color of the lizards simulates the color of the pine bark so closely that the collector is usually conscious only of movement, and has no impression of the outline of a lizard when he sees one at the height of its activity darting over or around a slab of bark. The lizards do not extend beyond the limit of the yellow pine on the dry south facing slopes, but are sometimes found in the brushy area at its border and here are most often seen foraging about the edges of outcroppings of rock. Individuals observed in this habitat showed little pigmentation and had an unusually pale ground color. They approximated the pale brown shade of the dry grass in which they were foraging.

Such color changes as occur in an individual *Gerrhonotus* are gradual and seemingly are not influenced by its mental state, the color of its surroundings, or the temperature. During the

early stages of growth, there is a gradual transition from the banded color pattern of the young (see pl. 2, fig. 1) to the adult pattern, which is already attained in half-grown individuals. Differences in amount of pigmentation were noticed among young of the same brood. Adult individuals of dark and light color extremes, which were kept together in captivity for periods of months, showed no perceptible color changes except for a gradual darkening of the general coloration and dulling of the pattern before ecdysis, followed by a corresponding brightening of the pattern and paling of the coloration after ecdysis.

San Francisco Alligator Lizard

Gerrhonotus coeruleus coeruleus

Because of the relatively uniform climate in its range this lizard apparently does not hibernate completely. Van Denburgh (1922, p. 445) tells of five being found hibernating in decaying logs at Pescadero, San Mateo County, on December 22, 1893, but he does not describe the condition of the lizards. During cold weather they apparently remain inactive and under cover but near the surface of the ground and ready to emerge whenever the air temperature becomes high enough for them to forage. On January 15, 1933, at Daly City, I found five specimens on the surface of the ground in a semi-active condition. At Bolinas Bay in Marin County, I found them active on February 14, 1932.

In spite of the long growing season in west-central California several years evidently are required for an individual to attain adult size. Young of various sizes may be found at all times of year. In those more than a year old there is probably overlapping in size between broods of successive years. The accompanying table based on specimens taken at Daly City shows roughly the rate of growth.

Table showing sizes of young Gerrhonotus c. coeruleus taken at Daly City, San Mateo Co., California

(Head and body lengths in mm.)

	First year young	Second year young (?)
August	31, 35, 38, 36, 38	55, 56, 58
September	35.5, 39, 39, 40, 41.5, 36, 36, 36, 39, 41, 41	64, 64, 67, 74
January	41.5, 47	67
February	38, 42, 43, 43	
March	43.5	50
April	41, 48	56, 56, 57, 59, 60, 62, 6
June	41, 41, 42	

Table showing stomach contents of Gerrhonotus c. coeruleus taken at Daly City, San Mateo Co., California

Number of specimens	9	11	9
Date	April 9, 1932	August 14, 1932	August 27, 1932
Stomach contents			
Coleoptera	24 carabid beetles 2 weevils	8 carabid beetles 1 silphid beetle	27 carabid beetles 1 grub
Lepidoptera	3 noctuid moths		
Orthoptera	1 Stenopelmatus (mandible only)	2 small Stenopelmatus 1 large Stenopelmatus (hind leg only)	1 grasshopper
Diptera	1 Ceuthophilus 1 crane fly	24 grasshoppers	
Hymenoptera	1 ichneumon wasp		3 wasps 1 small bee
Arachnida	3 spiders		4 spiders
Myriapoda		1 centipede	
Mollusca			1 snail

At Daly City, on August 14, grasshoppers were at the height of their abundance and were swarming on the open hillside where the lizards were taken. The lizards were then concentrating on them, while at other times small beetles formed the bulk of their diet. The presence of a single mandible in one stomach and a hind leg in another, both from large individuals of *Stenopelmatus,* are probably to be accounted for on the supposition that the lizards had first killed the insects, and after failing to swallow them whole had succeeded in breaking off and swallowing single appendages. This explanation is based on the behavior of captive individuals, which often killed insects that were too large to be swallowed entire by them.

Van Denburgh (1922: 445) records a pair of *coeruleus* found mating April 12, 1909, on Mussel Rock, San Mateo County. It is probable that the breeding season is limited to a brief period at this time of year. On April 10, 1932, two individuals, which I had collected at Daly City on the day before, were found mating in their cage at 1 p. m. Occasionally the female struggled to escape and at such time the male employed his prehensile tail in holding her. Copulation began at about 4:30 p. m. The female's body was bent at right angles in the middle, the male's was looped over and under it so that the hemipenis employed was on the side opposite to that on which the male held the female's head. Brief periods of sexual excitation, during which the male made copulatory movements and tapped the sacral region of the female with his hind foot, alternated with longer quiescent periods. They separated at 9:15 p. m.

In San Mateo County, where the two species are found together, the San Francisco Alligator Lizard evidently mates several weeks earlier than does the Red-backed Alligator Lizard. At Daly City, on August 14, 1932, young of *coeruleus* were seen in abundance, but apparently the young of *G. m. multicarinatus* had not yet hatched, as none at all was seen.

On one occasion when a large skink, *Eumeces skiltonianus,* and a young *G. c. coeruleus* were placed together in a cage, the skink ate the alligator lizard, swallowing it head first. Its tail was broken off and was not eaten.

Near Daly City, on September 18, 1932, the head and stomach (the latter filled with insect remains) of a *Gerrhonotus coeruleus* were found on top of a large boulder where they had evidently been discarded by some predator. Probably the lizard had been caught and eaten by a sparrow hawk, as one of these birds was seen on the same boulder earlier in the afternoon.

When a large adult male *coeruleus* was offered to a captive sparrow hawk, the bird flew down and caught it at once, taking it by surprise. The lizard twisted about, partly freed itself and bit at the hawk, which released it and jumped back. Renewing the attack a moment later the hawk hopped around the lizard, stamping its feet and preparing to strike. The *Gerrhonotus* made no attempt to escape but assumed a characteristic defensive attitude, standing high off the ground with its body thrown in an arc, head and tail pointing toward the bird and with its mouth open. It was breathing heavily with a faint whistling sound, which is characteristic of this species when angered. With a sudden forward spring it caught the bird across the base of the bill and held on tenaciously, while the bird fluttered and hopped backward across the cage clawing at the lizard in an attempt to free itself. After this the hawk was wary but finally approached again. The lizard sprang and seized its breast feathers. The hawk grasped the lizard with one foot, but they separated quickly. The hawk then avoided the lizard and remained in the opposite end of the cage until it had been removed. The lizard was apparently uninjured and its bony skin had not been penetrated by the hawk's talons.

Several kinds of snakes probably prey upon these lizards. A garter snake (*Thamnophis ordinoides atratus*) which I collected at Moss Beach, San Mateo County, had an adult in its stomach. Domestic cats have been seen to catch and kill them. At Daly City numbers of crushed individuals have been found on the road where they had been run over by automobiles. The charred remains of one were found at the base of a boulder where evidently it had perished in a grass fire.

Nematode worms are sometimes abundant in the stomach and intestines of these lizards. Flukes have been found in their

body cavities. Some individuals have colonies of orange-colored mites on the soft skin of the lateral fold; ticks are often found in or around the ear opening. There is no evidence that these parasites have any serious effect on the lizards.

Sierra Alligator Lizard

Gerrhonotus coeruleus palmeri

On June 23 and 24, 1932, I collected a series of this lizard in General Grant National Park, California. The weather was warm. Individuals were seen foraging in the middle of the morning and until late in the afternoon, but most of those found were under cover, usually beneath strips of yellow-pine bark which were lying on the ground or were loosely attached to dead trees and fallen logs. Other specimens were found on the bare rock beneath loose granite slabs. They were active and quick in their movements, often escaping even when uncovered in their hiding places. Perhaps because of the relatively scant cover, they seemed to run faster and for longer distances than do other forms of the species. The relatively larger feet of *palmeri* are probably correlated with its open habitat.

In escaping, the lizards usually took advantage of the downhill slope. When an attempt was made to noose one seen crawling through a dense tangle of *Ceanothus velutinus,* the lizard, attracted by the shiny copper wire, climbed rapidly toward it, struck, and then dropped to the ground where it escaped by burrowing in the litter of dry leaves and sticks.

Stomach contents of thirteen of the specimens taken were identified as follows: 33 small beetles, 1 grub; 11 bugs; 4 moths; 1 geometrid larva; 1 ant lion; 7 large termites; 1 large bumblebee; 1 ant; 1 small wasp; unidentified insect eggs; 2 pine needles (evidently taken accidentally with the food).

Stomach contents of an adult male from Merced Lake, 7500 feet, Yosemite Park, included a large moth, three termites, a small spider, and two small grubs.

Of the specimens examined the five which were molting when captured were taken during June, July, and August.

Van Denburgh (1922: 447) wrote that in Yosemite Valley *palmeri* mates about the middle of June. Of the three adult females taken by me in General Grant Park on June 23 and 24, 1932, only one (Mus. Vert. Zool., no. 15032) contained developing ova. These were four in number and averaged 8.5 x 7.5 mm. in size. Seemingly this would indicate a slow rate of reproduction in *palmeri.* Probably at the high altitudes where it is found, natural enemies are fewer and hence the

lifetime of an individual is longer. A small number of eggs would probably make for more rapid development of the embryos.

SUMMARY

Differences in habits exist between the two species of *Gerrhonotus* studied, and there are less marked differences among the subspecies of each, which apparently are correlated with the slight differences in structure.

Alligator lizards, in the region studied, range from the Lower Sonoran Life Zone to the Canadian Zone, inclusive. *G. coeruleus* occurs higher zonally than does *multi-carinatus*, but there is some overlapping between the two species in the Transition Zone. *Gerrhonotus multi-carinatus* is characteristically an inhabitant of the oak and chaparral belt in the foothills and valleys. *Gerrhonotus coeruleus* is typical of a cooler and more humid habitat, usually in the vicinity of coniferous forests. In this species individual variation is great, especially in color pattern; throughout its area of occurrence dark and light color extremes exist, with all stages of intergradation. Predominance of one color variety or the other seems to depend on local conditions and may be a direct result of natural selection.

Recorded methods of self-protection used by alligator lizards include hiding in holes or among dry leaves, or exceptionally, in the water; climbing into trees or bushes; using the tail as a decoy and escaping when it breaks while the enemy's attention is distracted by its writhings; crouching motionless until the danger has passed; repelling the attacker by ejecting the offensive smelling or tasting excreta; holding the tail in the mouth encircling a branch so that the body cannot be swallowed or moved by the enemy; taking the offensive and driving away the enemy.

Animals which have been recorded as preying upon alligator lizards include snakes (racers, rattlesnakes, garter snakes), Skilton's skink (in captivity), shrike, red-tailed hawk, and domestic cat.

Insects of the larger and more slowly moving types comprise the bulk of the diet; beetles, caterpillars, and grasshoppers are those most frequently taken. Snails, scorpions, and spiders are also eaten. Stinging and biting animals are preyed upon regularly, and although the sight of any small moving object stimulates the foraging lizard to attack, certain forms having offensive secretions seem to be habitually avoided. Small mammals and birds' eggs are occasionally eaten.

The breeding season apparently varies locally within each species, and the species differ in their time of mating when both

occur in the same locality. During mating the head of the female is held diagonally across the temporal region in the jaws of the male. Many hours are required for completion of the process. *Gerrhonotus coeruleus* is viviparous while *multicarinatus* is ovoviviparous and deposits eggs which require several weeks to hatch. Viviparity in *coeruleus* may be correlated with its colder and damper habitat.

Several months of each year are passed in hibernation by the alligator lizards of some localities, whereas in other localities hibernation is incomplete; individuals may be active on warm days, even during the winter.

These lizards are solitary in habits and show almost no trace of social behavior. Fighting is unusual among them but may occur between individuals competing for the same morsel of food (as observed with those kept in captivity), or between breeding males competing for the same female.

Captive individuals showed indications of learning, and formed habits rapidly. *Gerrhonotus* probably ranks high among reptiles in intelligence.

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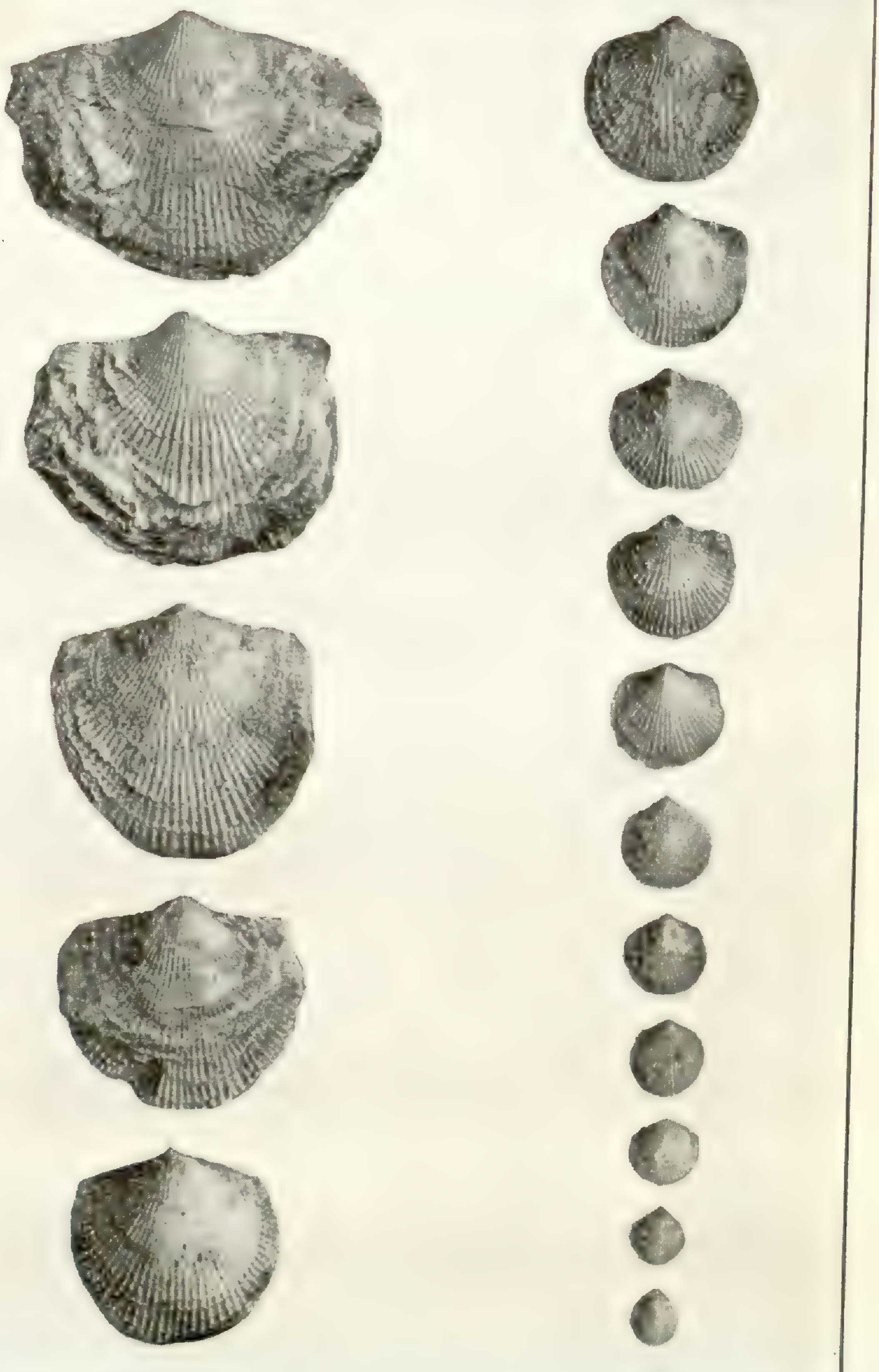
PLATE I.



Figs. 1—16. *Atrypa missouriensis* Miller.

1—16 Pedicle views of a series of this species from the Spirifer annae zone of the Callaway Limestone. Near Bellama Springs, Callaway Co., Mo.

Atrypae of the Central Missouri Devonian

D. K. Greger

Abstract.

This paper is offered with a view to giving a definite value to the various species of Atrypa found in the Devonian of Central Missouri.

Throughout the many reports of the Missouri Geological Survey, and elsewhere, the forms herein described are referred to as *Atrypa reticularis, Atrypa sp.*, etc.

Six species are recognized from the Central Missouri Devonian, three of which were orginally described from Iowa, two are here figured and defined as new species and the sixth—*Atrypa missouriensis* Miller, orginally described from immature specimens, is fully illustrated and its horizon definitely established.

ATRYPA MISSOURIENSIS MILLER

Plate 1, figs. 1—16.

Plate 2, figs. 1—6.

Atrypa missouriensis S. A. Miller, Indiana Dept. Geol. Nat. Res., 18th Rept. (Adv. sheets), p. 61, pl. 9, figs. 19—21.
Atrypa missouriensis S. A. Miller, Indiana Dept. Geol. Nat. Res., 18th Rept., p. 315, pl. 9, figs. 19—21, 1894.
Atrypa missouriensis Miller, Fenton and Fenton. American Midland Naturalist, Vol. 12, No. 1, 1930, p. 15, pl. 2, figs. 5—9.

Original Description. "Shell small, subcircular, rather longer than wide, valves very moderately and nearly equally convex, cardinal extremities rounded.

"Ventral valve most convex in the umbonal region, which is rather sharply rounded transversely, from which elevation the shell gently slopes to the front and the antero-lateral sides. Beak projects a little beyond the beak of the opposite valve, but is not incurved over it.

"Dorsal valve rather more evenly convex that the ventral,

without any defined mesial elevation, the greatest convexity being in the central part, from which it slopes nearly equally in all directions. Beak very small and extending slightly beyond the cardinal line, but not incurved.

"Surface marked by numerous very fine radiating striae that are crossed by a few concentric lamellose lines of growth".

OBSERVATIONS.

The type specimens of *Atrypa missouriensis* Miller were collected by R. A. Blair of Sedalia, Mo., in 1890 from a small outcrop of Callaway limestone on the La Mine River, near Otterville, Mo. Later Blair selected specimens of this and other associated fossils and forwarded them to S. A. (Sam) Miller of Cincinnati for identification. The original lot, excepting those sent to Miller, was acquired by the writer and later sent to E. M. Kindle for study. They are to be found in the National Museum, Ottawa, Canada, Catalogue number 6031.

With the large series collected at Otterville during the last season, it is recognized that Miller's types are immature specimens of the species. The average measurements of the species is as follows—length 28 mm.—breadth 33mm.—thickness 19 mm. —number of striae in the space of 5 mm. 7.

In a recent paper[1] it is stated that the types of *Atrypa missouriensis* "appear to have been found in the Cooper limestone near Otterville, 17 miles east of Sedalia, Missouri. No additional specimens that agree with Miller's figures have been found at this horizon."

The age of the bed from which Miller's *A. missouriensis* was collected has been determined by both the writer and McQueen, Assistant Director of the Mo. Geol. Survey, as division 2 of the Callaway.

The meager fauna of the Cooper Limestone has been recorded by the writer[2] but no species of Atrypa have been collected from it.

McQueen and the writer have collected abundant material of the species from the exposure within the last three years. The lithologic and faunal characters of this outcrop are identical with those of zone 2—Spirifer annae zone—of the type locality

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[1]*Fenton and Fenton, Studies on the genus Atrypa, Amer. Midland Naturalist, Vol. 12, page 15, 1930.*

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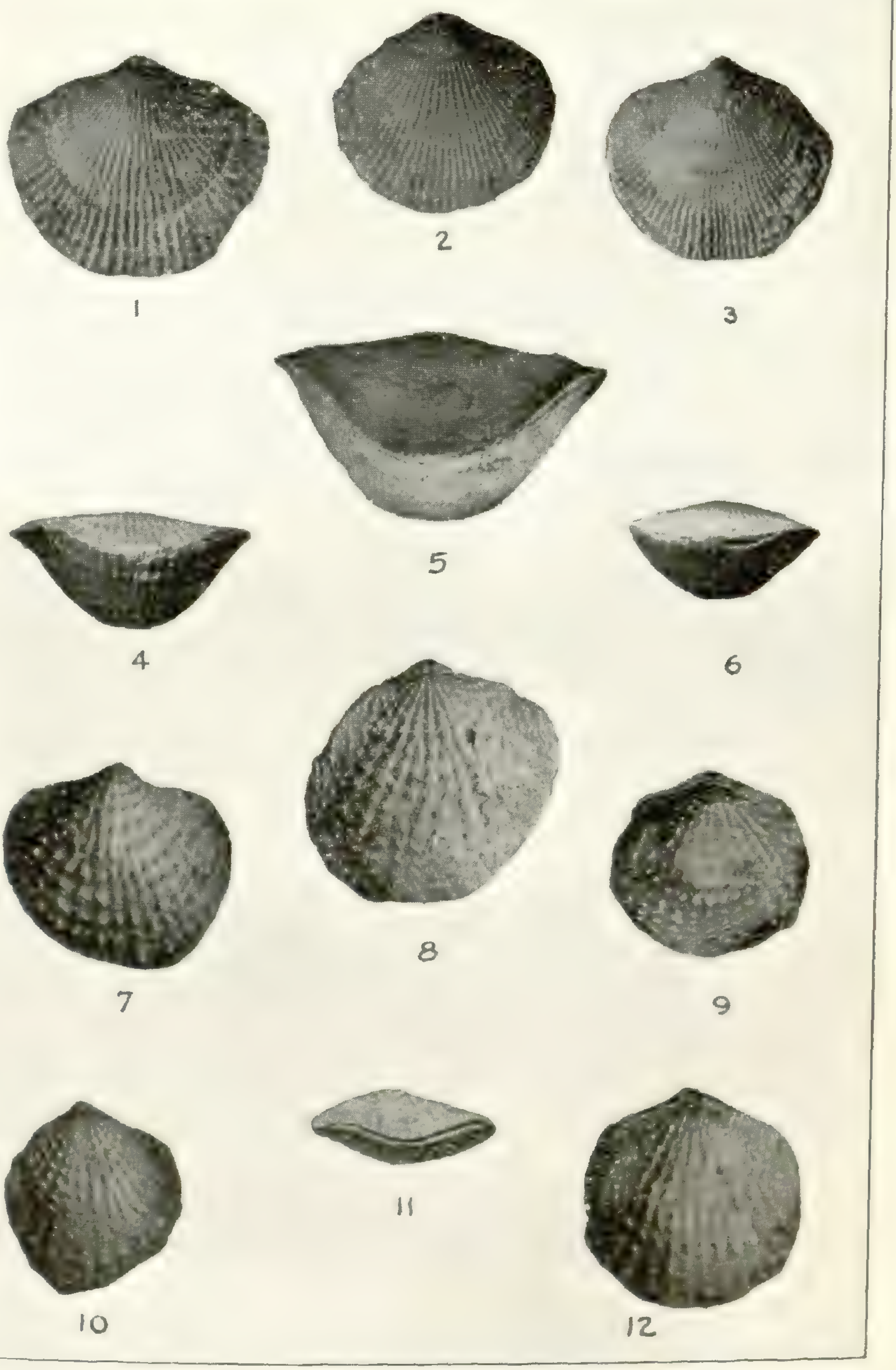
[2]*Greger, Amer. Journ. Sci., Vol. 50, July, 1920, pp. 20—24.*

PLATE II.



Figs. 1—6. *Atrypa missouriensis* Miller.

1, 2, 3, Views of three pedicle valves. 4, 5, 6, Anterior views of three individuals, all from the Callaway Limestone, east of Otterville, Cooper Co., Mo., on the La Mine River.

Figs. 7—12 *Artypa planosulcata* Webster

7. Pedicle view of an average example. 8, 9. Brachial views of two similar shells. 10. Brachial view of a young specimen. 11. Anterior view of fig. 9. 12. Brachial view of plump, well preserved example.

of the Callaway Limestone at Bellama Springs, Callaway Co., Mo., and the three species—*Atrypa missouricnsis* Miller, *Spirifer annae* Swallow, and *Athyris fultonensis* Swallow are the characteristic fossils of this zone at both localities[3].

ATRYPA PLANOSULCATA WEBSTER

Plate 2, figs. 7—12.

Atrypa hystrix planosulcata Webster, 1888. American Naturalist, Vol. 22, p. 1104.

Atrypa planosulcata Webster, Fenton and Fenton, 1924. Michigan Univ. Cont. Museum Geol., Vol. 1, p. 139, pl. 27, figs. 13—16.

Atrypa planosulcata is common in the lower third of the Snyder Creek Shale—Strophonella zone. It first appears in a thin, soft, brown layer directly above the basal Gomphoceras zone and continues upward for about thirty inches, at which place most of the Brachiopods drop out to be succeeded by an abundance of Bryozoans and Corals. A careful study of a large series of this species, made during the summer of 1934, from both Central Missouri and Iowa localities show no differential characters, except in condition of preservation and the slightly smaller size of the Missouri shells. Swallow[4] identified the Missouri shells in 1864 as *A. hystrix* Hall. Greger[5] recorded it in a faunal list of the Central Missouri Devonian as *A. hystrix occidentalis* Hall, and Branson[6] figures it in his Missouri Devonian as *A. spinosa* Hall, from the Snyder Creek Shale, but fails to state that it occupies a very limited zone near the base of the formation.

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[3]*Athyris ottervillensis Miller and Athyris brittsi Miller, are known to be immature specimens of Athyris fultonensis Swallow. Fully mature and typical examples of Athyris fultonensis Swallow have been collected from the Otterville exposure.*

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[4]*Swallow, Catalogue of the Boyce Collection, 1864.*

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[5]*Greger, Amer Jour. Sci., Vol. 27, p. 376, 1909.*

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[6]*Branson, Mo. Geol. Surv., Vol. 17, Series 2, p. 98, pl. 20, fig. 8, pl. 23, figs. 8, 9.*

ATRYPA DEVONIANA WEBSTER, FENTON & FENTON

Plate 3, figs. 1—5

Atrypa devoniana Webster, 1921. American Midland Naturalist, Vol. 7, p. 19.

Artypa devoniana Webster, Fenton & Fenton, 1924. Michigan Univ. Cont. Museum of Geol. Vol. 1, p. 134, pl. 26, figs. 16—24.

Artypa devoniana Webster, Fenton & Fenton, 1932 American Midland Naturalist, Vol. 13, pl. 21, fig. 5.

In Missouri, *Atrypa devoniana* occurs only in the gray, soft, sandy upper member of the Snyder Creek Shale, associated with *Atrypa snyderensis* Greger, *Cyrtina triquetra* Hall, *Productella callawayensis* Swallow, and a large species of Spirifer commonly referred to *S. euryteines* Owen.

Branson has figured a specimen of *A. devoniana* as *A. reticularsis*, Mo. Geol. Survey, Vol 17, pl. 23, fig. 12, the shell in question coming from the upper beds of the Snyder Creek shale.

The Snyder Creek specimens before me are identical with a series of this species from the Hackberry Grove locality in Iowa. Along with the fine striae—9 in the space of 5 mm.—the narrow, deep U shaped sinus is an outstanding character.

Average measurements of twenty mature specimens of *A. devoniana* from the Snyder Creek shale of Missouri is as follows—length 20 mm., breadth 22.5 mm., thickness 13 mm.

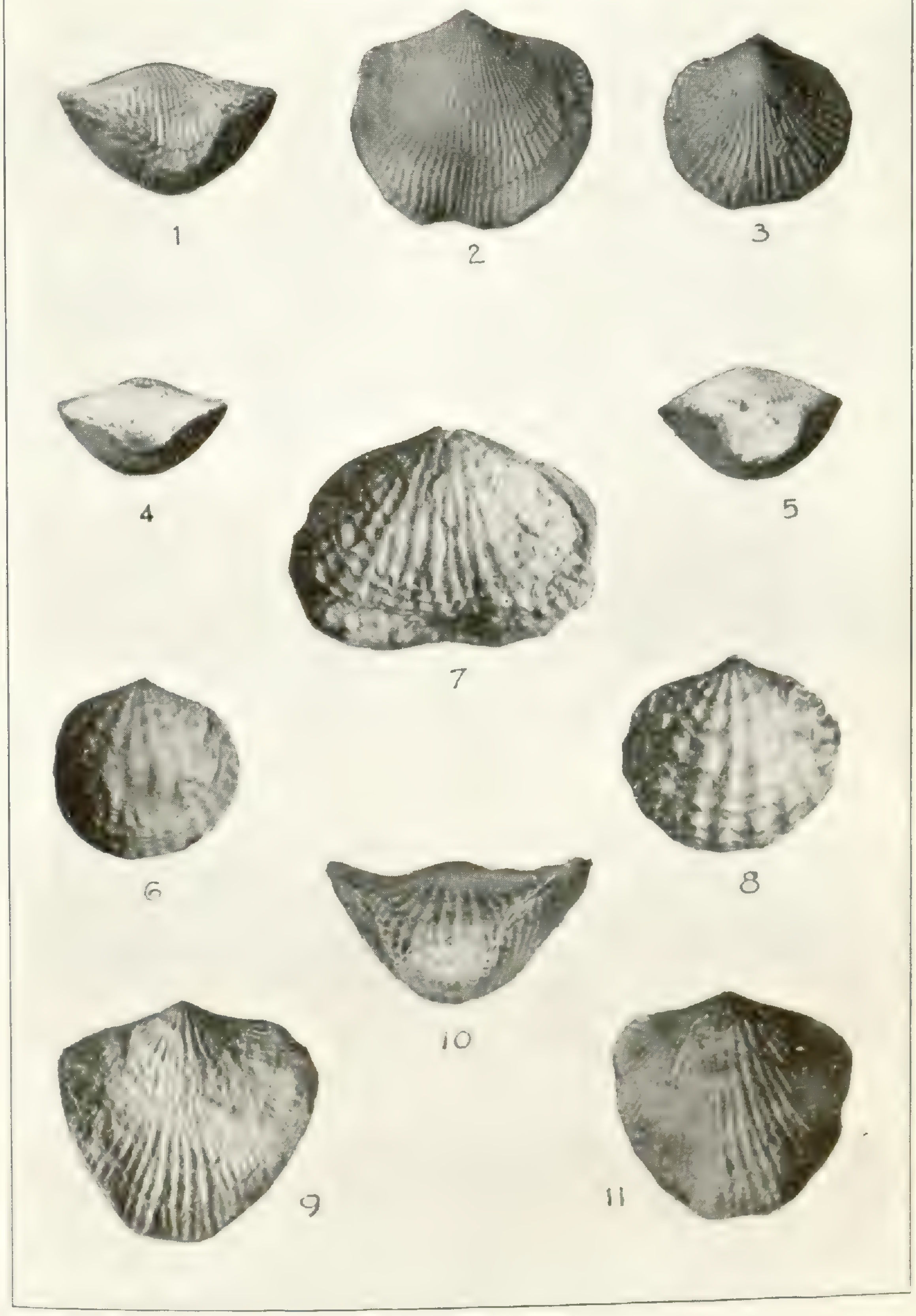
ATRYPA ROCKFORDENSIS FENTON & FENTON

Plate 3, figs. 6, 7, 8.

Altrypa rockfordensis, Fenton & Fenton, 1924. Michigan Univ. Cont. Mus. Geol., Vol. 1, p. 142, pl. 27, figs. 4—12.

Atrypa rockfordensis is not abundant in the Snyder Creek shale. However, in a zone of almost 4 inches, near the base of the upper third of the shale, it is found in numbers, but only as separated valves. It first appears in the Snyder Creek in a thin yellow to brown layer, directly above the crinoidal limy shale member and is associated with *Stropheodonta navalis* Swallow,

PLATE III.



Figs. 1—5 *Artypa dovoniana* Webster.
1. Anterior view of an average example. 2, 3. Pedicle views of two well preserved specimens. 4, 5. Anterior views of two young shells, both showing the characteristic U shaped sinus.

Figs. 6—8 *Atrypa rockfordensis* Webster.
6. Brachial view of an average shell. 7. Pedicle view of a crushed gerontic shell, note the thickened margins. 8. View of a well presented brachial valve.

Figs. 9—11 *Atrypa callawaycnsis*, spec. nov.
9. Pedicle view of the largest specimen collected. 10. Anterior view of the shell. 11. Brachial aspect of same.

Stropheodonta inflexa Swallow, *Leiorhynchus sp. nov.* and the rare crinoid—*Dactylocrinus concavus* (Rowley).

Branson[7] figures *A. rockfordensis* in his Devonian of Missouri, but refers the species to *A. hystrix* Hall and its stratigraphic position in the Snyder Creek is not given.

Average measurements of a series of the best preserved material in the collection give the following: length 23.7 mm., breadth 27mm., thickness (of conjoined valves) 11.3 mm., number of striae in space of 5 mm. 2—3.

ATRYPA CALLAWAYENSIS SP. NOV.

Plate 3, figs. 9, 10, 11.

Shell longitudinally subovate in outline, gibbous, strongly inequivalve, hinge line short, cardinal extremities rounded, greatest breadth of valves just formward of the posterior third of the shell.

Pedicle valve the smaller, convex in the umbonal region but deeply sinuate in the anterior portion.

Brachial valve convex in the posterior portion but developing a medial fold which becomes quite prominent in the anterior one third, an upward flexing of the lateral margin of the valve, gives a somewhat winged expression to the shell in some specimens.

The exterior of both valves is covered with fine radiating striae four or five to the space of 5 mm. Striae are increased, both by implantation and bifurcation. A few ill defined concentric lines of growth appear at intervals on the valves but growth varices are only feebly developed. Structurally the shells are very thin; undistorted examples with conjoined valves are rare. Measurements of ten specimens average as follows: length 26 mm., breadth 26 mm., thickness 13 mm., number of striae in the space of 5 mm. 5.

This species is found only in the lower third of the Snyder Creek Shale, —Strophonella zone—where it is associated with

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[7]*Missouri Geol. Survey, Vol. 17, Series 2, pl. 20, figs. 9, 10, 11, and pl. 23, fig. 7.*

Schizophoria macfarlaini Meek, *Spirifer amarus* Swallow, *Productella marquessi* Rowley, *Cranaena morsii* Greger, *Athyris minima* Swallow, *Strophonella crassa* Rowley, many Stropheodontas, Bryozoans and Corals.

ATRYPA SNYDERENSIS SP. NOV.

Plate 4, figs. 1—5.

Shell of medium size for the genus, sub-circular to ovoid in outline, biconvex, length and width almost equal. Hinge line less than the width of the shell. Cardinal extremities rounded. Brachial valve ventricose, frequently quite gibbous, its greatest convexity at or directly forward of the umbo.

The surface is ornamented by strong, rounded or sub-angular plications which are increased by bifurcation and implantation, crossed by lamellose, imbricating concentric lines of growth. These lamellar growths are extravagantly developed in most individuals, frequently equaling, and occasionally surpassing, the length of the valves proper. Figure 5, pl. 4 shows an artificial preparation in which all but the marginal lamella has been removed, revealing the shape and size of the shell.

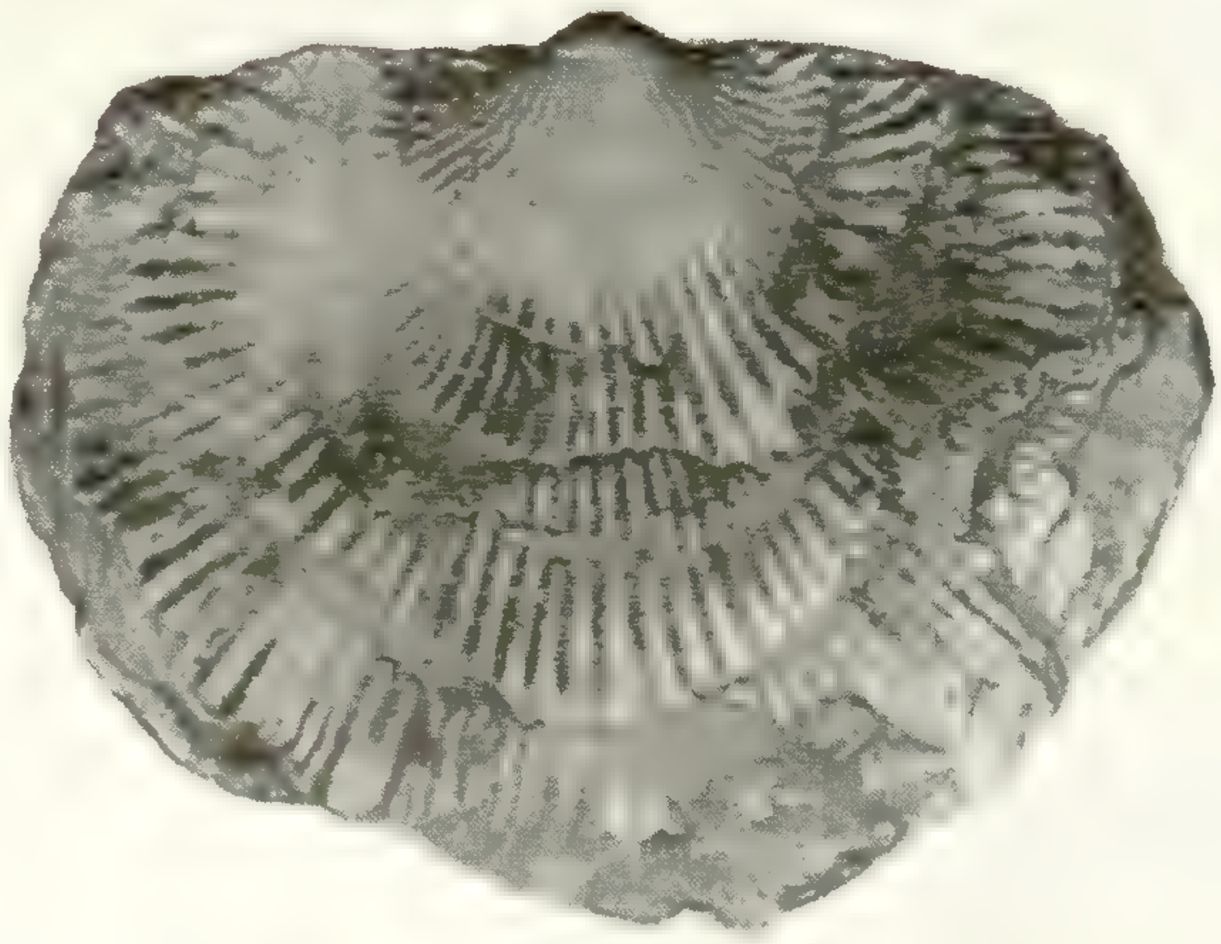
The lamellae are very thin (0.3 mm.), continuous, fluted plates and do not coelace one with another. They frequently bifurcate along the outer edge and in rare instances implantation occurs, simulating the surface of the underlying shell surface.

Measuremens of a series of specimens divested of their extravagantly developed "frills" average: length 31 mm., breadth 30mm., thickness 17 mm.

The largest specimen of this species in our collection—length and breadth 85mm. with the growth varices removed, measures: length 36 mm., breadth 35 mm. Figures 5 pl. 4 shows a specimen with all but the marginal fringe removed.

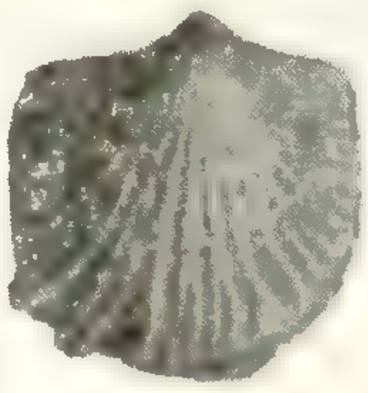
Atrypa snyderensis is found only in the Upper Snyder Creek; it is always associated with the following species: *Spirifer euryteines, Productella callawayensis, Cyrtina triquetra, Stropeodonta callawayensis, Stropheodonta quadrata,* and many internal casts of Pelecypods.

PLATE IV.

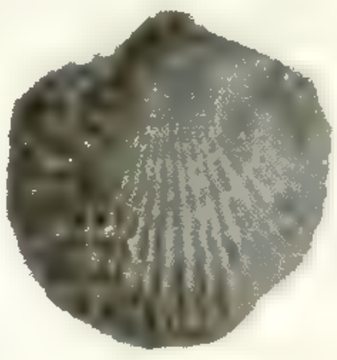


1

2



3



4

5

Figs. 1—5 *Atrypa snyderensis* spec. nov.

1. Pedicle view of a very perfect shell. 2. Pedicle view of a young shell. 3. Brachial view of a young shell. 4. Brachial view of a very young example, enlarged. 5. Pedicle view of a large example with the shell removed except the marginal varice.

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VOLUME XXIX, No. 3.

Outline of a Theory of Functions of an Abstract Variable

SOLOMON BILINSKY

Issued October 30, 1936

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Outline of a Theory of Functions of an Abstract Variable

SOLOMON BILINSKY

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Outline of a Theory of Functions of an Abstract Variable

The object of this paper is simply to develop, in outline, a theory of functions, analytic in the same sense as that used in the theory of the complex variable, but for a variable whose range may have as wide a meaning as possible. In the problem of integration, however, we need not be restricted to analytic functions. More precisely formulated, the aim is to develop mathematical operations so that very general types of equations of identity $F(x)\equiv 0$ which may occur in ordinary analysis are both significant and true in those domains of analysis for which the operations are defined. These domains occur as common illustrations of the Banach space.

The linear vector space. This comprises the ordinary linear abstract space involving elements, called vectors or points, and three functional operations: addition, scalar multiplication, and forming the norm. We shall write the well-known governing postulates, partly for completeness, and partly to allow a pertinent comment.

Let E represent the space; x, y, z, vectors in E; and ξ, η, complex numbers, it being assumed that the associated number system, denoted by C, is complex. We shall use the ordinary symbols of arithmetic for addition and scalar multiplication.

P.1. $x+y$ is a function on E to E, called addition.

P.2. $x+y=y+x$

P.3. $(x+y)+z=x+(y+z)$

P.4. $\xi\cdot x$ is a function on C and E to E, called scalar multiplication.

P.5. $\xi\cdot x=x\cdot\xi$

P.6. $1\cdot x=x$

P.7. $\xi\cdot(x+y)=x\cdot\xi+\xi\cdot y$

P.8. $(\xi+\eta)\cdot x=\xi\cdot x+\eta\cdot x$

P.9. $(\xi\cdot\eta)\cdot x=\xi\cdot(\eta\cdot x)$

P.10. $\|x\|$ is a function on E to the positive real number

system, called the norm.

P.11. If there is an element whose norm is zero, it is unique.

P.12. $\|\xi \cdot x\| = |\xi| \cdot \|x\|$

P.13. $\|x+y\| \leqq \|x\| + \|y\|$

It is possible to show that the postulates are consistent, and that P.2 and P.9 may be proved from the remaining ones, which are independent among themselves.

The element $(-x)$ is defined as $(-1) \cdot x$.

Neighborhood. The set of points x, which satisfy the inequality

$$\|x - x_0\| < \rho > 0,$$

where x_0 is a given element, and ρ a given positive number, is called the ρ neighborhood of x_0. The element x_0 is called the *center* of the neighborhood.

Region. If every point of a given set R is the center of a neighborhood which belongs to the set, then R is called a region.

Connected region. Let x_0 and x_1 be any two points of a region R. If there exists a chain of neighborhoods, finite in number, all contained in R, and such that each neighborhood contains the center of the succeeding one, with x_0 being the first center and x_1 the last, then R is said to be *connected*. The set of points $x_0, \cdots, x_1$ that serve as centers for the neighborhoods of the chain is called the route of the chain.

Simply-connected region. Let x_0 and x_1 be any two points of a connected region R, and C and C' any two chains that extend from x_0 to x_1. Then if we can replace C by a succession of chains such that the neighborhoods of each chain contain the route of the previous chain, and if after a finite number of steps we arrive at C', R is said to be simply-connected.

Limit point. A set of points E_0 of E is said to have a limit point x_0 if it contains points different from x_0 in every ρ neighborhood of x_0.

Convergence. An infinite sequence of elements $\{x_n\}$ is said to converge to a limit x_0 if for every ρ greater than zero, there corresponds an integer n_ρ, such that for all $n > n_\rho$, $|x_n - x_0| < \rho$.

Completeness. We now add another postulate so that the space considered becomes a complete linear vector, or Banach, space.

P.14. In order that a sequence $\{x_n\}$ converges, it is sufficient that for every $\rho > 0$ there exists an integer n_ρ such that for all $n > n_\rho$ and all $\rho > 0$,

$$\| x_{n+p} - x_n \| < \rho.$$

The elementary theorems which show the existence of a zero element, uniqueness of the limit, unique solvability of linear equations, etc., are well-known and we shall not bother to state them.

The generalized vector space. We consider the following postulates as a basis for the ensuing analysis.

I. For every positive integer n and including 0 there exists a complete linear vector space $E_{(n)}$, containing elements $x_{(n)}$.

II. There exists an operation called vector multiplication, which has the following properties.

P.15. For $m \neq 0$, $n \neq 0$, $m \geqq n$, $x_{(m)}y_{(n)}$ is a function on $E_{(m)}$ and $E_{(n)}$ to $E_{(m+n-2)}$.

P.16. $(\xi \cdot x_{(m)})(\eta \cdot y_{(n)}) = (\xi \cdot \eta) \cdot (x_{(m)}\, y_{(n)})$.

P.17. $x_{(m)}(y_{(n)} + z_{(n)}) = (x_{(m)}y_{(n)}) + (x_{(m)}x_{(n)})$.

P.18. $(x_{(m)} + y_{(m)})z_{(n)} = (x_{(m)}z_{(n)}) + (y_{(m)}z_{(n)})$.

P.19. $x_{(m)}(y_{(n)}z_{(p)}) = (x_{(m)}y_{(n)})z_{(p)}$, $n \neq 1$.

P.20. The equation $x_{(m)}a_{(n)} = b_{(m+n-2)}$, $a_{(n)} \neq 0$, has at least one solution for $x_{(m)}$.

P.21. $\| x_{(m)}y_{(n)} \| \leqq \| x_{(m)} \| \cdot \| y_{(n)} \|$.

P.22. $x_{(1)}y_{(1)} = y_{(1)}x_{(1)}$.

A system having the properties stated in I and II is called a generalized vector space.

Notation. Evidently we have not overtly distinguished between various types of addition and multiplication. The exact operation will always be clear from the nature of the elements involved; as well as the meaning of the symbol 0, which will also acquire a unique significance in its context. For convenience, elements $x_{(1)}$ of $E_{(1)}$ will be more simply denoted by x, leaving the letter free for other distinguishing subscripts.

Continuity. A function $f(x)$ on $S (S \subseteq E_{(i)})$ to $S' (S' \subseteq E_{(j)})$ is said to be continuous on S if for every $\eta > 0$ there exists a δ depending, in general, upon η and x, such that $\| y - x \| < \delta$, where $y \in S$, implies that $\| f(y) - f(x) \| < \eta$. If δ is independent of x, then $f(x)$ is said to be uniformly continuous throughout S.

The M-function. A function $f(x)$ on S to S', as above, is called an M-function if there exists a sequence of sets of points in $E_{(i)}$ denoted by $\{S_n\}$, where $S_n \subseteq S_{n+1}$ and S is the outer limiting set of the sequence, such that $f(x)$ is continuous on S_n for every n. It is not difficult to see that if S is a region in a space E which possesses a Lesbegue measure and each S_n is

measurable, then an M-function is measurable.

In the majority of cases the proofs of theorems which we shall now begin to state are omitted because they are to be carried through in exactly the same way as the corresponding theorems in ordinary analysis. In other cases we shall assume that the proof is of sufficient novelty or interest to be given explicity. Also, we shall state a theorem with great care only when it is considered to be of sufficient importance to do so.

T.1. The scalar multiple of an M-function (or continuous function) is an M-function (or continuous function).

T.2. The sum of two M-functions (continuous functions) is an M-function (continuous function).

T.3. The product of two M-functions (continuous functions), providing the product has meaning, is an M-function (continuous function).

T.4. An M-function (continuous function) of an M-function (continuous function) is an M-function (continuous function).

T.5. If $f_n(x)$ on $S_n (S_n \subseteq E_{(i)})$ to $S' (S' \subseteq E_{(j)})$ is an M-function, and if $\{f_n(x)\}$ is convergent to $f(x)$ on T $(T \subseteq \Pi^{\infty} S_n)$, where $\Pi^{\infty} S_n$ indicates the "durchschnitt" of the sequence, then $f(x)$ is an M-function on T to S'.

Proof: From the fact that $\{f_n(x)\}$ is convergent it follows that there exists a sequence of sets $\{T_n\}$ with T as its outer limiting set, and such that $\{f_n(x)\}$ is uniformly convergent on each T_m. To prove this let $\{\rho_{(k)}\}$ be a sequence of positive numbers tending to zero, and $\{n_k(\rho_k, x)\}$ the corresponding sequence of integers associated with $\{f_n(x)\}$, such that $\|f_n(x) - f(x)\| < \rho_k$ whenever $n > n_k(\rho_k, x)$. Let T_1 be the set of points for which $n_k(\rho_k, x)$ is bounded as x travels over T, and when $n_{1k}(\rho_k)$ is the least upper bound. The sequence $\{n_{1k}(\rho_k)\}$ then satisfies the condition that $\{f_n(x)\}$ be uniformly convergent on T_1. By steps, increasing the value of the upper bound, we obtain the desired sequence $\{T_m\}$. The theorem is now obvious on taking into account the fact that a uniformly convergent sequence of continuous functions converges to a continuous function.

Nullifying elements. We say that $a_{(n)}$ is a nullifying element if $a_{(n)}x = 0$ for every x in $E_{(1)}$. However it is quite sufficient for $a_{(n)}x$ to vanish in some neighborhood of $x = x_0$, say whenever $\|x - x_0\| < \rho$. For if this be true, whatever y may be, $a_{(n)}y = 0$, because we may write $\alpha a_{(n)}y = a_{(n)}(\alpha y + x_0)$, and we may choose α so that $\|\alpha y\| < \rho$.

If the norm of $a_{(n)}$ is so defined that in the inequality

$$\|a_{(n)}x\| \leqq \|a_{(n)}\| \cdot \|x\|,$$

which holds for all x and every $a_{(n)}$, there exists some value of x not zero for which the equality is true, we shall say that that norm is the most effective norm. In this case we have the theorem that if the norms of all the elements of $E_{(n)}$, for all n, are the most effective, the only nullifying element is the zero vector. When the norm is the most effective, two vectors which differ by a nullifying element are identical, otherwise they are merely equivalent with respect to multiplication.

Multilinear functions. Let $x_1, x_2, \cdots, x_n$ denote a set of independent variables whose range is $E_{(1)}$ (note that the subscripts above are not in parentheses).

We shall say that a function $f(x_1)$ on $E_{(1)}$ to $E_{(n)}$ is homogeneous of the nth degree if for all ξ and x_1

$$f(\xi x_1) = \xi^n f(x_1);$$

and linear homogeneous if

$$f(\xi x_1) = \xi f(x_1)$$

$$f(x_1 + x_2) = f(x_1) + f(x_2)$$

for all x_1 and x_2.

It is readily seen that $a_{(n)}x_1$ is a linear homogeneous function which is also uniformly continuous. Since the product is an element of $E_{(n-1)}$ for each value of x_1, we may multiply it on the right by x_2 of $E_{(1)}$ and so obtain the function $a_{(n)}x_1x_2$ on $E_{(1)}^2$ to $E_{(n-2)}$. This function of two independent variables is linear homogeneous in each, and it is therefore called bilinear. It is, moreover, uniformly continuous in both variables if their range is a bounded region.

In a similar manner it is possible to consider the multilinear function with n independent variables which is generated by successive multiplication on the right:

$$a_{(n)}x_1x_2x_3 \cdots x_n \quad \text{on} \quad E_{(1)}^n \quad \text{to} \quad E_{(0)},$$

but we shall be chiefly interested in this function only when $x_1 = x_2 = \cdots = x_n$. It is then called a monomial of degree n.

Symmetric elements. The element $a_{(n)}$, $n \geqq 2$, is called a symmetric element if the function

$$a_{(n)}x_1x_2 \cdots x_n$$

is independent of the order of the variables $x_1, x_2, \cdots, x_n$. In the subsequent pages it will be assumed that every element which enters the analysis is, symmetric, since most important applications may be reduced to this case.

The Space $E_{[n]}$. We have seen that the function $a_{(n)}x$, where $a_{(n)}$ is a constant element of $E_{(n)}$, is linear homogeneous in x. Let us now suppose that $a_{(n)}$ is no longer constant, but is dependent upon x in such a way that the following conditions are satisfied. (This dependence is indicated by the notation $a_{(n)}(x)$, and so to prevent confusion multiplication will be distinguished by a dot between factors).

(1) $a_{(n)}(\xi x) = a_{(n)}(x)$ for all values of ξ and x;

(2) $a_{(n)}(x+y)\cdot(x+y) = a_{(n)}(x)\cdot x + a_{(n)}(y)\cdot y$ for all values of x and y.

It is quite evident that these functional relations are ad hoc sufficient to insure that the function $a_{(1)}(x)\cdot x$ be linear homogeneous in x. This suggests the consideration of the aggregate of values of $a_{(1)}(x)$, for every x in $E_{(1)}$, as a single object. As a further generalization it is possible to consider the totality of all such objects which are equivalent with respect to multiplication, i.e., which differ by nullifying elements, as a single object itself, to be distinguished, say, by a subscript enclosed in brackets. Thus $a_{[1]}$ is the class of aggregates of elements equivalent to $a_{(1)}(x)$, x ranging over $E_{(1)}$, which satisfy conditions (1) and (2).

It is natural to suppose that we shall define similar objects $a_{[n]}$ for every positive integer n. In this more general case the elements $a_{[n]}$ are vectors whose components are fixed by n parameters, i.e., $a_{[n]}$ is the class of all aggregates equivalent to $a_{(n)}(x_1, x_2, \cdots, x_n)$, satisfying conditions (1) and (2), and the additional requirement that $a_{(n)}(x_1, x_2, \cdots, x_n)$ be symmetric in every pair of its arguments. Letting $a_{[2]}$ and $b_{[2]}$ represent two such elements, we make the following definitions, which are applicable, of course, for any positive value of n.

$a_{[2]} + b_{[2]} \equiv$ the class of all aggregates equivalent to $a_{(2)}(x, y) + b_{(2)}(x, y)$.

$\xi a_{[2]} \equiv$ the class of all aggregates equivalent to $\xi a_{(2)}(x, y)$

$a_{[2]}x \equiv a_{(2)}(x, y)\cdot x$, and thus is a function on $E_{(1)}$ to a set of vectors with one-parameter components.

If, in addition, we adjoint the definitions of neighborhood and limit point that appear on p. 3, and assume that every element has a norm, we say that such elements $a_{[n]}$, corresponding

to a definite value of n, belong to a space $E_{[n]}$. It is not difficult to show that for $a_{[n]}$ to have a norm, it is necessary and sufficient that $a_{[n]}x_1 \cdot x_2 \cdots x_n$, on $E_{(1)}{}^n$ to $E_{(0)}$ be continuous in all of its arguments. One may then easily verify by reference to the postulates P.1 to P.14 inclusive that the following theorem is true.

T.6. The space $E_{[n]}$ is a complete linear vector space.*

The extension of the operation of multiplication to the spaces $E_{[n]}$ necessitates a restriction, which is one, however, that will not limit the theory in its intended development. The product $a_{[m]}b_{[n]}$, $m \geqq n$, is obviously to be defined as the aggregate of products $a_{(m)}(x_1, x_2, \cdots, x_m) \cdot b_{(n)}(y_1, y_2, \cdots, y_n)$, with one restriction that the product is to be limited to an aggregate that depends upon $(m+n-2)$ parameters at most. However, in order that the product satisfy the conditions (1) and (2) when these are extended for several variables, in addition to the condition of symmetry, it is also necessary to impose the restriction that multiplication is only to be allowed between elements $a_{[n]}$ and $b_{[n]}$ when

$$a_{[n]}(x_1, \cdots, x_i, \cdots, x_m) \cdot b_{[n]}(y_1, \cdots, y_j, \cdots, y_n) = a_{[m]}(x_1, \cdots, y_j, \cdots, x_m) \cdot b_{[n]}(y_1, \cdots, x_j, \cdots, y_n).$$

Having now satisfied the conditions (1) and (2) extended in addition to that of symmetry, it follows that there exists an element in $E_{[m+n-2]}$ which is equal to the product $a_{[n]}b_{[n]}$. We must be careful to note that *any* two elements, one in $E_{[m]}$, and one in $E_{[n]}$, $m \geqq n$, are not multiplicable, so that whenever a product appears in what follows, it will have been tacitly assumed that the product has a meaning, in other words, that the elements involved are multiplicable.

Let us suppose that we have a function of the sort $a_{[n]}xb_{[n]}$ on $E_{[1]}$ to $E_{[m+n-2]}$, with $a_{[m]}$ and $b_{[n]}$ both multiplicable elements. For definiteness, let us take $m = 3$, $n = 2$, say. Multiplying on the right by y and then by z, we may consider the product, according to the associative law, as given by $a_{[3]}x\{b_{[2]}y\}z$. Because of the symmetry, we have

$$\begin{aligned} a_{[3]}x\{b_{[2]}y\}z &= a_{[3]}\{b_{[2]}y\}xz \\ &= \{a_{[3]}b_{[2]}\}yxz \\ &= c_{[3]}xyz, \end{aligned}$$

* It is apparent now that $E_{(n)}$ is essentially a subspace of $E_{[n]}$; i.e., the subspace of vectors all of whose components are equal.

where $c_{[3]} = a_{[3]}b_{[2]}$. Accordingly, it follows that

$$a_{[3]}xb_{[2]} = c_{[3]}x,$$

and generally, that there exists a sort of commutativity among the factors of a product which are multiplicable among themselves.

It is also easily seen that if two vectors are multiplicable, and the second is multiplicable with a third, then the product of the first two is multiplicable with the third. Obviously, multiplicability is immediately extensible to the sum and scalar product of a set of multiplicable vectors.

For completeness $E_{[0]}$ is defined to be identical with $E_{(0)}$.

It is a simple matter now to verify the fact that the spaces $E_{[n]}$ satisfy, with the exception of P.20, all the postulates for a generalized vector space.

General multilinear forms. We have the following theorems.

T.7. The most general linear continuous homogeneous function on $E_{(1)}$ to $E_{(n-1)}$ is a function of the form $a_{[n]}x$, where $a_{[n]}$ is an element of the space $E_{[n]}$.

Proof. Because of P.20, for a fixed value of x, say x_0, we may solve the equation

$$u_{(n)}x_0 = f(x_0)$$

for $u_{(n)}$, where $f(x_{(0)})$ is the given function which is linear continuous homogeneous. For all choices of x we obtain a set of elements $u_{(n)}(x)$ that have the properties (1) and (2). Hence the aggregate $u_{(n)}(x)$ defines an element $u_{[n]}$, which, since $f(x)$ is continuous, belongs to the space $E_{[n]}$, being a vector, all of whose components but one are equal.

T.8. An arbitrary linear homogeneous function on $E_{(1)}$ to $E_{(n-1)}$ which may or may not be continuous, is an M-function.

Proof. As in the previous theorem, if $f(x)$ represents the given function we can find an aggregate of elements in $E_{(n)}$, namely $a_{(n)}(x)$, which satisfies (1) and (2), so that

$$a_{(n)}(x) \cdot x = f(x)$$

for all x. Obviously the norm of $a_{(n)}(x)$ is a function of x, which, because $f(x)$ is not assumed continuous may not be bounded. Let $\{\mu_i\}$ be a sequence of positive numbers tending monotonically toward infinity. Let S_i be the set of points in $E_{(1)}$ for which the inequality

$$\|a_{(n)}(x)\| \leqq \mu_i$$

is satisfied. Evidently $f(x)$ is continuous on S_i, because $a_{(n)}(x) \cdot x$ is, and the sequence $\{S_i\}$ has for its outer limit the space $E_{(1)}$. Hence, from the definition, $f(x)$ is an M-function.

By an easy generalization of T.7. it is possible to deal with the case of several variables. Thus, we have

T.9. If $f(x_1, x_2, \cdots, x_r)$, a function on $E_{(1)}{}^r$ to $E_{(n-r)}$, is linear continuous homogeneous in each variable, and uniformly so for all values of the remaining ones, and if, moreover, it is symmetric in every pair of elements, then there exists an element $a_{[n]}$ of $E_{[n]}$ such that

$$f(x_1, x_2, \cdots, x_r) = a_{[n]}x_1x_2 \cdots x_r.$$

Proof. If we consider $f(x_1, x_2, \cdots, x_r)$ as a function of x_r alone from the previous theorem we have

$$f(x_1, x_2, \cdots, x_r) = a_{[n-r+1]}x_r$$

for all values of x_r, where $a_{[n-r+1]}$ is a function of the remaining variables, which has the same properties as the given function. Considering any particular value of x_r and $a_{[n-r+1]}$ as a function of x_{r-1} alone. we again reproduce the conditions of T.7, so that we may write

$$a_{[n-r+1]}(x_1, x_2, \cdots, x_r) = a_{[n-r+2]}x_{r-1}.$$

This holds for the particularly chosen value of x_r, and on considering the aggregate of all values of x_r, we obtain an aggregate of vectors containing $a_{[n-r+2]}$. This aggregate, however, defines a single vector in $E_{[n-r+2]}$ with one more variable component than $a_{[n-r+2]}$. Then, on carrying out the procedure of complete induction, we have finally

$$f(x_1, x_2, \cdots, x_r) = a_{[n]}x_1x_2 \cdots x_r.$$

From the continuity of the function, it may be seen that the norms of the coefficients successively determined are well-defined, and consequently that

$$\|f(x_1, x_2, \cdots, x_r)\| \leqq \|a_{[n]}\| \cdot \|x_1\| \cdots \|x_r\|.$$

*Polynomials.** A function on $E_{(1)}$ to $E_{[n-r]}$, of the form

$$a_{[n]}x^r + a_{[n-1]}x^{r-1} + \cdots + a_{[n-r+1]}x + a_{[n-r]}$$

is called a polynomial of degree r, provided, of course, that $a_{[n]}$

* For other definitions of abstract polynomials see the note at the end of this paper.

is not a nullifying element. It is natural that the binomial theorem should hold also for abstract polynomials.

T.10.

$$a_{[n]}(x+y)^r = a_{[n]}\left\{\sum_0^r \binom{r}{s} x^{r-s}y^s\right\}.$$

The derivative. Let $y=f(x)$ be defined for a region R, and let it be continuous at the point $x=x_0$. Then $f(x)$ is said to have a differential at x_0 if there exists a function $f'(x_0)dx$, linear continuous homogeneous in dx, such that for $\delta>0$

$$\|f(x_0+dx)-f(x_0)-f'(x_0)dx\| < \delta\|dx\|$$

when $\|dx\|$ is sufficiently small. We write

$$dy \equiv f'(x)dx,$$

and dy is called the differential of $f(x)$ at x, provided, of course, that it exists.

It may be seen from the definition that dy is an element in the same space as y. If this space is $E_{(n)}$, then according to T.7 $f'(x)$ is an element of $E_{[n+1]}$. This element is called the derivative and will be denoted sometimes by dy/dx. Obviously the derivative is the analogue of the derivative in the theory of the complex variable, where there as well as here, the essential feature is that the "direction" of dx as $\|dx\|$ tends to zero is immaterial. Thus, as is well known, if the differential exists, it may be obtained as

$$\frac{d}{d\xi}f(x+\xi dx)\Big|_{\xi=0}$$

for any choice of dx.

If $f(x)$ is differentiable at x we may write

$$f(x+dx) = f(x)+f'(x)dx+\|dx\|\cdot e(x,dx),$$

where $\|e(x,dx)\|<\delta$ for $\|dx\|$ sufficiently small. In general, δ will depend upon x. When, however, it does not, we shall say that $f(x)$ is uniformly differentiable in the given range.

The following theorems are elementary.

T.11. If $f(x)$ and $g(x)$ are differentiable, and if

$$h(x) = f(x)+g(x)$$

then

$$h'(x) = f'(x) + g'(x).$$

T.12. If $f(x)$ is differentiable, and α is a scalar, then

$$\{\alpha f(x)\}' = \alpha f'(x).$$

T.13. If $f(x)$ and $g(x)$ are differentiable, and if

$$h(x) = f(x) \cdot g(x)$$

then

$$h'(x) = f(x) \cdot g'(x) + f'(x) \cdot g(x),$$

provided, of course, that the factors are multiplicable.

T.14. If the derivatives of $f(x)$ and $g(x)$ exist and are multiplicable, and if $z = f(y)$, where $y = g(x)$, then

$$\frac{dz}{dx} = \frac{dz}{dy}\frac{dy}{dx}.$$

As an illustration, we remark that the derivative of $a_{[n]}x^r$ is simply $r \cdot a_{[n]}x^{r-1}$, where r is, of course, a positive integer.

Curves. We shall be concerned with the class of linear continua that are described as rectifiable Jordan curves without multiple points, which, for brevity, we shall call uniform curves. There exists a relation of order between the points of such curves, this order relation being denoted by the customary signs $<$, and $>$. A uniform curve Γ, having a first point a and a last b, and containing these points is termed the uniform arc Γ_{ab}, and its length is denoted by γ_{ab}. This length is determined by means of a system of nets defined as follows: Let $a_1, a_2, \cdots, a_n$ be n arbitrary points on Γ_{ab}, satisfying the condition that

$$a < a_1 < a_2 < \cdots < a_n < b.$$

Such a subdivision is called a net of order n, and an infinite sequence of nets corresponding to the sequence of positive integers $\{n\}$ is called a system when between any two points of a net there are points which belong to every net of order $n >$ some n_0.

By the oscillation ω_{ab} of a uniform curve Γ between two of its points a and b, we shall mean the least upper bound of $|x-y|$ where the range of x and y is the arc Γ_{ab}.

An important theorem concerning uniform arcs is the following.

T.15. If Γ_{ab} is a uniform arc it is possible to subdivide it so that if a_i and a_{i+1} are any two successive points of the net, then $\omega_{a_i a_{i-1}} \leqq \delta$ for any $\delta > 0$. This is the well-known Borel property.

Integrability-R. Let $f(x)$ be bounded in a region R, in which there is defined a uniform arc Γ_{ab}. Let a system of nets be applied to the arc and consider the sum S_r, where

$$S_r = \sum_{0}^{r+1} f(x_i')(x_{i+1} - x_i), \qquad (A)$$

and where x_i, x_{i+1} are points of a net of the system, such that $x_0 = a$ and $x_{r+1} = b$, and $x_i \leqq x_i' \leqq x_{i+1}$. If the sequence $\{S_r\}$ has a limit S that is independent of the system of nets applied, $f(x)$ is said to be integrable-R along Γ_{ab}, and S, which is then called the line or curvilinear integral is denoted by

$$\int_{\Gamma a}^{b} f(x)dx$$

By the oscillation of $f(x)$ between two points d_i and d_{i+1} of Γ_{ab} we shall mean the least upper bound of $\|f(y) - f(x)\|$ for $d_i \leqq y$, $x \leqq d_{i+1}$. The function $f(x)$ is said to be continuous on the curve at a point x_0 if x_0 is interior to an interval for which the oscillation of $f(x)$ is arbitrarily small. When the maximum oscillation over the set of intervals of Γ_{ab} in a system of nets approaches zero as the order of the net increases, and this is true for all systems, then $f(x)$ is said to be uniformly continuous on Γ_{ab}. These definitions are, of course, only special cases of continuity and uniform continuity as previously defined.

We have the following theorems.

T.15. A function which is continuous on a uniform arc is also uniformly continuous on the arc.

T.16. A function which is continuous on a uniform arc is also integrable-R on the arc.

The proof of this theorem does not follow that ordinarily given in the theory of the real variable, in defining an upper and lower Riemann integral, but follows, rather, a modified form which does not make use of these auxiliary integrals.

T.17. The elementary properties of the curvilinear integral are expressed by the following equations:

$$(1)\qquad \int_a^b f(x)dx = -\int_b^a f(x)dx$$

$$(2)\qquad \int_a^b f(x)dx + \int_b^c f(x)dx = \int_a^c f(x)dx$$

$$(3)\qquad \int_a^b \alpha f(x)dx = \alpha \int_a^b f(x)dx$$

$$(4)\qquad \int_a^b \{f(x) + g(x)\}dx = \int_a^b f(x)dx + \int_a^b g(x)dx.$$

T.18. Let $f(x)$ be a bounded integrable-R function and let μ be its upper bound. Then we have

$$\left\| \int_{\Gamma a}^b f(x)dx \right\| \leqq \mu\gamma_{ab}$$

T.19. If $f_n(x)$ is continuous on a uniform arc and if $\{f_n(x)\}$ converges uniformly to $f(x)$ on the arc Γ_{ab} then

$$\lim \int_a^b f_n(x)dx = \int_a^b \lim f_n(x)dx = \int_a^b f(x)dx.$$

Integrability-L. We have considered the integrability of functions which are defined for every point of a given arc; in fact for a whole region containing the arc, and in this connection we have found that the class of continuous functions is integrable-R. It is possible, however, to extend the notion of integrability to the class of M-functions by the following broadening of our conception, which in its application reduces essentially to the Lesbegue-Stieltjes integral.

If in the application of a system of nets to an arc we remove the restriction that the number of subdivisions is finite, and then form the sum (A) for a function defined over the arc, we may speak of the lower limit of the sum for all systems of nets; that is, for all modes of subdivision. If the function is defined only over a set of points S contained in the arc we omit all those intervals from (A) which do not contain points of S. On the other hand, we may consider the upper limit of the sum when we omit all those intervals which are not contained in S. If these two limits exist and are equal, the function is said to be integrable-L.

T.20. A function which is integrable-R is also integrable-L and the two integrals are equal.

The proof of the next theorem follows that of T.16 very closely.

T.21. If $f(x)$ is continuous and bounded on a set of points S on a uniform arc Γ_{ab} it is integrable-L on Γ_{ab}.

The characteristic function $\phi(x)$ for a set S is defined to be 1 when x belongs to S and 0 otherwise. Accordingly, the measure of a set S which lies on the arc Γ_{ab} is then defined by the equation

$$\mu(S) = \int_{\Gamma a}^{b} \phi(x) \| dx \| ,$$

where we assume that the right hand member is self-explanatory. It is seen, for instance, that the measure of Γ_{ab} itself is γ_{ab}.

The following theorems, analogous to those concerning functions continuous on the whole of Γ_{ab}, are proved in a similar manner.

T.22. Let $f(x)$ be a bounded integrable-L function, and let λ be its least upper bound on a set S of a uniform arc Γ_{ab}. We then have

$$\left\| \int_{\Gamma a}^{b} f(x) dx \right\| \leqq \lambda \mu(S)$$

T.23. If $f(x)$ is a bounded M-function on a uniform arc and the sets of the sequence over which it is continuous are measurable, it is integrable-L on the arc. (The proof follows readily from the last theorems and the lemma: If S is the outer limit of $\{S_n\}$ then $\mu(S) = \lim \mu(S_n)$ if S_n is measurable for every n).

The integral of $a_{[m]}x^r$. The calculation of this integral must be carried out in a different manner from that ordinarily employed, for here it must be done directly.

The integral of $a_{[m]}x^r$. Let Γ_{ab} be a uniform arc in $E_{(1)}$; we shall show that

$$I = \int_{\Gamma a}^{b} a_{[m]} x^r dx = \frac{a_{[m]}}{r+1} (b^{r+1} - a^{r+1}) .$$

Let

$$S_{n,s} = a_{[m]} \sum_{0}^{n+1} x_i^{r-s} x_{i+1} (x_{i+1} - x_i) \tag{1}$$

where $x_0 = a$, $x_{n+1} = b$, and s is a positive integer $\leqq r$; then it will first be shown that

$$\lim S_{n,0} = \lim S_{n,s} \text{ for each } s. \tag{2}$$

We have

$$x_{i+1} = x_i + (x_{i+1} - x_i)$$

and

$$x^s_{i+1} = \sum_{0}^{s} \binom{s}{t} x_i^{s-t} (x_{i+1} - x_i)^t .$$

Substituting this in (1) we obtain

$$S_{n,s} = S_{n,0} + \sigma .$$

Where every term in σ is of the type

$$(A) = \sum_{0}^{n+1}{}_{i} \binom{s}{t} x_i^{r-t}(x_{i+1} - x_i)^{t+1}, \qquad t = 1, 2, \cdots, s.$$

Thus there are a finite number of terms of this type, s of them, in fact. Each term approaches zero as n increases for the norm of $(A) \leqq \max_i \| x_i^{r-t}(x_{i+1} - x_i)^t \| \gamma_{ab}$, where γ_{ab} is the length of Γ_{ab}, and its coefficient becomes vanishingly small. This proves (2).

Now on forming the sum $\sum_{0}^{r}{}_{s} S_{n,s}$ it is seen that alternate terms cancel each other, so that

$$\sum_{0}^{r}{}_{s} S_{n,s} = a_{[m]} \sum_{0}^{n+1} (x_{i+1}^{r+1} - x_i^{r+1}) = a_{[m]}(b^{r+1} - a^{r+1}),$$

and this is true for every value of n. But by definition we have

$$I \equiv \lim S_{n,0}$$

and an account of (2)

$$\lim \sum_{0}^{r}{}_{s} S_{n,s} = (r+1) I.$$

Hence

$$I = \frac{a_{[m]}}{r+1}(b^{r+1} - a^{r+1}),$$

which was to be proved.

It is worthy of notice that the integral is independent of the path from a to b, so that if the uniform arc is closed, that is, $a = b$, the integral vanishes.

Infinite series. Let $\{a_i\}$ be an infinite sequence of elements all of which belong to some space $E_{[m]}$, and let us denote the sum of the first n terms by S_n, that is,

$$S_n = a_1 + a_2 + \cdots + a_n .$$

Then the infinite series

$$a_1 + a_2 + \cdots + a_n + \cdots$$

is said to converge to the sum S if the sequence $\{S_n\}$ converges to S.

The series is said to converge absolutely if the corresponding series of positive numerical terms

$$\|a_1\| + \|a_2\| + \cdots + \|a_n\| + \cdots$$

converges.

There are two very useful theorems in connection with absolute convergence; namely,

T.24. If an infinite series converges absolutely, it converges.

T.25. A derangement of the terms of an absolutely convergent series does not alter the sum of the series.

If each of the terms of an infinite series is a function of x, we may denote the series by $\sum_0^\infty f_i(x)$, where x has some given range. We define $S_n(x)$ by the equation

$$S_n(x) = \sum_0^n f_i(x)$$

and if $\{S_n(x)\}$ converges uniformly, then the infinite series is said to converge uniformly over the given range. The Weierstrass M-test, as expressed in the following theorem is useful.

T.26. If for all values of x in a given range R, the norms of the terms of a series $\sum_0^\infty f_i(x)$ are respectively less than the corresponding terms in a convergent series of numbers $\sum_0^\infty \mu_i$, where μ_i is independent of x, then $\sum_0^\infty f_i(x)$ is uniformly convergent in R.

Power series. An infinite series of the form

$$a_{[r]} + a_{[r+1]}x + \cdots + a_{[r+n]}x^n + \cdots$$

is called a power series. For those values of x where the series converges there is defined a function on $E_{[1]}$ to $E_{[r]}$. We shall be interested in the properties of this function, but it is of primary importance to determine the range of x for which the series has a meaning. This we proceed to do.

Let $\bar{x}_0$ be a unit element of $E_{[1]}$, that is, an element whose norm is 1. The aggregate of values for which $x = \xi\bar{x}_0$, ξ being a variable complex number, is called the complex-plane determined by $\bar{x}_0$, or, more simply, the $\bar{x}_0$ complex-plane. On fixing the argument of a power series to the complex-plane determined by some fixed unit element $\bar{x}_0$, we have the theorem

T.27. The series $\sum_0^\infty \{a_{[r+n]}\bar{x}_0^n\}\xi^n$ converges uniformly and absolutely for all values of ξ such that

$$|\xi| < \underline{\lim} \left\| a_{[r+n]}\bar{x}_0^n \right\|^{-1/n},$$

and diverges when

$$|\xi| > \underline{\lim} \left\| a_{[r+n]}\bar{x}_0^n \right\|^{-1/n}.$$

The right-hand member of these inequalities, which we denote by $\rho^-{}_0$, is called the radius of convergence in the $\bar{x}_0$ complex-plane. On considering the totality of unit elements in $E_{[1]}$, and on applying the Weierstrass M-test, we can easily see the truth of the following theorem.

T.28. If $\rho_{\bar{x}}$ is the radius of convergence in the $\bar{x}$ complex-plane for a given power series, and if ρ is the greatest lower bound of ρ^{-} as $\bar{x}$ varies over all unit elements in $E_{[1]}$, then the series converges uniformly and absolutely for all values of x for which $\|x\| < \rho$.

The positive number ρ, which may also be 0 or ∞, is called the radius of uniform convergence. The name is justified by the following theorem, whose proof is obvious.

T.29. Let ρ be the radius of uniform convergence of a given power series, and α a positive number such that $\alpha > \rho$. Then there exists some x such that $\|x\| = \alpha$ and for which the series diverges.

The aggregate of values for which a series converges uniformly may be referred to as the sphere of convergence.

Regular functions. A function $f(x)$ is said to be regular at the point $x = x_0$ if it is equal to a power series $\sum_0^\infty a_{[r+n]}(x-x_0)^n$ everywhere within the interior of a sphere whose center is at x_0 and whose radius ρ is greater than zero. In this ρ neighborhood of x_0, such a function possesses certain regular properties, some of which are disclosed in the following theorems. The proofs of these theorems are, as we expect, identical in form with their analogues in the theory of the complex variable; therefore, as usual, we omit them.

T.31. If $f(x)$ is regular at the point $x = x_0$ it is regular at every point interior to the sphere of convergence of its representative power series.

T.32. Let $f(x)$ be regular at $x = x_0$, and let ρ be the radius of uniform convergence of the representative power series. Also let $\{x_i\}$ be an infinite sequence of points such that whatever be n and the unit element $\bar{x}$ there is always a term x_i, $i > n$, such that $x_i = \xi\bar{x}$ for some ξ, and such that the sequence has x_0 for a limit point. If $f(x) = 0$ on every point of the sequence $\{x_i\}$ then $f(x) = 0$ throughout the sphere of convergence. (It may easily be seen that in order to carry the proof through in the same fashion as the corresponding theorem in ordinary analysis, it is necessary to strengthen the hypothesis as we have done).

Corollary I. Let $f(x)$ and $g(x)$ be regular in the neighborhood of a point $x = x_0$ and equal over such an infinite set of points as described above. Then $f(x) = g(x)$ throughout the neighborhood.

Corollary II. If $f(x)$ is regular at the point $x = x_0$, and there exist two power series such that in a neighborhood of x_0.

$$f(x) = \sum_0^\infty a_{[r+n]}(x - x_0)^n = \sum_0^\infty b_{[r+n]}(x - x_0)^n,$$

then $a_{[r+n]} = b_{[r+n]}$ for all n.

T.33. If $f(x) = \sum_0^\infty a_{[r+n]}(x - x_0)^n$ throughout the sphere of convergence of the right-hand member, then the derivative $f'(x)$ is also regular in the same region and $f'(x) = \sum_0^\infty n a_{[r+n]}(x - x_0)^n$.

T.34. If $f(x) = \sum_0^\infty a_{[r+n]}(x - x_0)^n$ throughout the sphere of convergence of the right-hand member, and Γ_{ab} is a uniform arc entirely within this sphere, then

$$\int_{\Gamma a}^{b} f(x)dx = \sum_0^\infty \int_{\Gamma a}^{b} a_{[r+n]}(x - x_0)^n dx$$

$$= \sum_0^\infty \frac{1}{n+1} a_{[r+n]} \left\{ (b - x_0)^{n+1} - (a - x_0)^{n+1} \right\}$$

or,

$$\int_{\Gamma a}^{b} f(x)dx = F(b) - F(a),$$

where $f(x) = F'(x)$.

In T.33 it was seen that a function which is regular is differentiable. Does the converse hold? The answer, which is in the affirmative, may be found from a theorem established by Gateaux.* He has shown that a function which is differentiable throughout the ρ neighborhood of a point may be expressed by an infinite series $\sum_0^\infty U_n(x - x_0)$ which converges uniformly in the given neighborhood, and is such that $U_n(x - x_0)$ is a function of the form discussed in the Note (see p. 37), and called by Gateaux a homogeneous polynomial of order n. But we have seen that such a function, on $E_{[1]}$ to $E_{[r]}$ for instance, may be expressed in the form $a_{[r+n]}(x - x_0)^n$; therefore, the given function may be represented by a power series $\sum_0^\infty a_{[r+n]}(x - x_0)^n$, which converges uniformly for $\|x - x_0\| < \rho$. On combining this result with T.33 we have

T.35. A necessary and sufficient condition that $f(x)$ be regular in a neighborhood of a given point is that it be differentiable in the neighborhood.

Moreover, Gateaux's result proves a sort of a converse to T.21, for it shows that if $f(x)$ is regular at every point inside a

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* *Sur diverses questions du calcul fonctionelle*, Soc. math. de France Bull., p. 21, vol. L, 1922.

sphere of radius ρ and center x_0, then it is expressible in terms of a power series about x_0, with a sphere of convergence equal to ρ. In other words the sphere of convergence extends up to a point where the function ceases to be regular—an important observation in connection with the process of "continuation."

Since we may differentiate a power series any number of times at points within the sphere of convergence, we have for a function $f(x)$, regular in the neighborhood of a point $x = x_0$, Taylor's formula:

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + \frac{1}{2!} f''(x_0)(x - x_0)^2 + \cdots .$$

Continuation. Let $\sum_0^\infty a_{[r+n]}(x-x_0)^n$ be a given power series with a radius of uniform convergence equal to $\rho_1 > 0$. Then if we have

$$f_1(x) \equiv \sum_0^\infty a_{[r+n]}(x - x_0)^n; \qquad \|x - x_0\| < \rho_1$$

the function thus defined is regular throughout the whole range R_1 of its definition. Now let x_1 be some value of x within this range and consider the function $f_2(x)$ where

$$f_2'(x) \equiv \sum_0^\infty{}_n \left\{ \sum_0^\infty{}_k \binom{n+k}{k} a_{[r+n+k]}(x_1 - x_0)^k \right\} (x - x_1)^n,$$

The latter series has a radius of uniform convergence $\rho_2 \geqq \rho_1 - \|x_1 - x_0\|$, so that $f_2(x)$ is well defined for a range R_2 that lies partly, at least, within R_1.

The function $f_2(x)$ is called a *continuation* of the *element* $f_1(x)$ if R_2 lies partly outside of R_1, otherwise we obtain nothing new. By forming all continuations (this of course is not actually possible, but the conception is assumed allowable in the construction of a class) of the original element $f_1(x)$, then all continuations of these continuations, and so on, we construct an aggregate of functions that we denote by $f(x)$. This function is said to be *generated* by the element $f_1(x)$. Its range is the sum of the ranges of the functions that comprise the aggregate, and its values are those of the same functions; hence, in general, $f(x)$ is not single-valued. We shall call $f(x)$ the *extended regular function.*

T.36. The extended regular function generated by a given element $f_1(x)$ is identical with that generated by any among the

chain of continuations of $f_1(x)$.

Proof. Let $f_i(x)$ be a power series obtained by continuation from $f_1(x)$, necessarily in a finite number of steps. Denoting the range of $f_i(x)$ by R_i, we have

$$f(x) = f_i(x), \qquad x \epsilon R_i,$$

Now beginning with $f_i(x)$ as an element we can reverse the process, and obtain $f_1(x)$, and consequently all the continuations of $f_1(x)$ and their subsequent continuations. This proves the theorem.

We may now call any element $f_i(x)$, as well as $f_1(x)$, of the aggregate defining $f(x)$ a generating element of the extended regular function.

T.37. If the range of an extended regular function is a simply-connected region R the function is single-valued everywhere in R.

Proof. It is sufficient to show that if we continue an element $f_1(x)$ along two different routes between any two points x_0 and x_1 we obtain the same value for $f(x)$ at the terminus.

Now since R is simply-connected we can replace one chain running from x_0 to x_1 by a succession of chains such that the neighborhoods of each contain the route of the previous one. It follows from an application of the uniqueness theorem (Corollary I to T.32) that with each succeeding chain we arrive at x_1 with the same value of $f(x_1)$, and since we can pass from one of our chains to the other in a finite number of steps the theorem is proved.

T.38. A necessary and sufficient condition that $f(x)$ be an extended regular function is that it be differentiable in a connected region R.

Proof. The theorem is a consequence of T.25 and the definition of an extended regular function by continuation.

It is similarly possible to extend other properties of power series throughout a connected region obtained by continuation. Thus from T.22 we get

T.39. Let $f(x)$ be an extended regular function in a region R, which vanishes on an infinite sequence of points such as is described in T.22. Then $f(x) = 0$ throughout R.

Singularities. If a function $f(x)$ is regular on a sequence of points which has x_0 say, for a limit point, but is not regular at x_0 itself, it is said to be singular at x_0, and the point is called a *singularity* of the function. With this terminology we can re-

state some of previous assertions in a new manner, as for instance, the remarks following T.78 tell us that a power series has at least one singularity on its sphere of convergence.

For any point in the space $R_{[1]}$ an extended regular function is regular, singular, or is such that it is not defined at all in the neighborhood of the point. The fact that this last condition may hold means that we have not been able to continue the given function everywhere, and therefore that there may be some boundary beyond which we cannot pass.

Such a boundary is called a natural boundary of the function.

By confining the range of the argument of a given power series to some complex-plane $x = a$, with a variable complex parameter ξ, it may be found, perhaps, that as a function of ξ in this plane, the power series has a natural boundary. If, moreover the power series is a function on to the complex number system, we have an ordinary analytic function $f(\xi)$, whose domain of existence is a region in the a complex-plane, at least partly bounded. With the process of continuation as just developed for the abstract variable it may be possible to extend the definition of $f(\xi)$ beyond its natural boundary in the complex domain by means of a route that passes outside of the a complex-plane. This process would afford the same kind of generalization as that involved in passing beyond an interval of convergence in the domain of the real variable and into the domain of the complex variable.

However, since there are any number of abstract analytic functions which have identical values throughout a given complex plane, this way of extending a function of a complex variable beyond its natural boundary is not unique, unless one chooses for some good reason, a particular abstract power series as a generalizing function. Perhaps in choosing a power series which are solutions of a generalized form of Laplace's differential equation, one may find good reason in the analogy with the complex power series.

We can be certain that the radius of convergence $\rho_{\bar{x}}$, considered as a function of $\bar{x}$, is not continuous. (If it were, continuation beyond a natural boundary in a complex-plane would be a fortiori impossible). Consider the following example.

Let $E_{(1)}$ be the space of functions continuous in the interval $(0, 1)$, $E_{(0)}$ the space of complex numbers, and let the norm of $x \equiv x(t)$ be defined as $\max_{0 \leqq t \leqq 1} |x(t)|$. In particular consider the one parameter set of functions, or unit elements, t^a, where

$\alpha \geqq 0$, and define $a_{[n]}\bar{x}^n$, as a function on $E_{(1)}$ to $E_{(0)}$, to be the integral

$$n! \int_0^1 \int_0^{t_1} \cdots \int_0^{t_{n-1}} (t^\alpha)^n dt\, dt_{n-1} \cdots dt_1.$$

As for $a_{[n]}$, we need only note that by assigning it the norm 1, and observing that the norm of t^α is also 1, the inequality

$$\left\| a_{[n]}\bar{x}^n \right\| \leqq \left\| a_{[n]} \right\| \cdot \left\| \bar{x} \right\|^n = 1$$

is satisfied. For brevity, denote $a_{[n]}\bar{x}^n$ simply by $\bar{x}^n$. We can perform the integration indicated above, obtaining

$$\bar{x}^n = \frac{n!\Gamma(\alpha n)}{\Gamma(\alpha n + n)} = B(\alpha n, n).$$

For the infinite series $\Sigma_0^\infty x^n = \Sigma_0^\infty \bar{x}^n \xi^n$, where $x = \xi\bar{x}$, we have

$$\sum_0^\infty x^n = \sum_0^\infty B(\alpha n, n)\xi^n.$$

Here we have a one parameter family of regular functions, with the parameter α. The radius of convergence at $\alpha = 0$ is, of course, 1, for $B(0, n) = 1$. We will show that $\rho_{\bar{x}}$ at $\alpha = 0$, i.e., at $\bar{x} = 1$, is discontinuous.

From the definition

$$\rho_\alpha = \lim_{n \to \infty} B(\alpha n, n)^{-1/n}.$$

We know

$$B(\alpha n, n) \sim \sqrt{2\pi e}^{1/2 \log (\alpha+1)/\alpha n + n\alpha \log \alpha/(\alpha+1) + n\alpha \log 1/(\alpha+1)}$$

$$B(\alpha n, n)^{-1/n} \sim \sqrt{2\pi} \left(\frac{\alpha n}{\alpha + 1} \right)^{1/2n} \left(\frac{\alpha + 1}{\alpha} \right)^\alpha (\alpha + 1)$$

and hence

$$\rho_\alpha = \sqrt{2\pi} \left(\frac{\alpha + 1}{\alpha} \right)^\alpha (\alpha + 1).$$

We have seen that $\rho_{\bar{x} \equiv 1} = 1$, but from the last equation it is seen that $\lim_{\alpha \to 0} \rho_{\bar{x}} = \sqrt{2\pi}$. Hence $\rho_{\bar{x}}$ is discontinuous at $\bar{x} \equiv 1$.

Additional properties of regular functions.

T.40 (Cauchy's theorem). Let $f(x)$ be a single-valued regular function in a connected region R, and let Γ be a closed uni-

form curve contained in R. Then

$$\int_\Gamma f(x)dx = 0.$$

Proof. Since $f(x)$ is an extended regular function (see T.38), it follows that the curve may be separated into a finite number of arcs on each of which the function is represented by a single power series. If there are n such arcs we may write

$$\int_\Gamma f(x)dx = \int_{\Gamma x_0}^{x_1} f(x)dx + \int_{\Gamma x_1}^{x_2} f(x)dx + \cdots + \int_{\Gamma x_{n-1}}^{x_0} f(x)dx$$

where $x_0, x_1, \cdots, x_{n-1}$ mark the end points of the arcs, and applying the result of T.34 to each integral, we find that the terms cancel each other in succession.

In particular, of course, the curve Γ may lie entirely within a fixed complex-plane and in this case we have also the formulas proved by Gateaux (assuming $f(x)$ to be regular at $x = 0$ for convenience):

$$f(x) = \frac{1}{2\pi i}\int_\Gamma \frac{f(\xi x)d\xi}{\xi},$$

which holds for all $x \epsilon R$ if Γ encloses the origin; and in the same region

$$a_{[r+n]}x^n = \frac{1}{2\pi i}\int_\Gamma \frac{f(\xi x)}{\xi^{n+1}}d\xi$$

Gateaux has also proved the following theorem

T.41. If

$$f(x) = \sum_0^\infty a_{[r+n]}x^n; \qquad \|x\| < \rho$$

and $\mu(\rho_1)$ is the least upper bound of $\|f(x)\|$ on the sphere $\|x\| = \rho_1$, then

$$\|a_{[r+n]}\bar{x}^n\| \leqq \frac{\mu(\rho_1)}{{\rho_1}^n}$$

for all values of n and all x.

From this last we may deduce a theorem analogous to that of Liouville, namely:

T.41. A function which is regular and bounded throughout

the whole space $E_{(1)}$ is a constant.

The fundamental theorem of the integral calculus. It is apparent from Cauchy's theorem (T.40) that if $f(x)$ is a single-valued regular function in a connected region R, then the integral

$$\int_{z_0}^{z} f(x)dx$$

taken along a uniform contour from z_0 to a variable point z and lying entirely within R is independent of the path so chosen. The integral is therefore a function of z alone. We have the following theorem.

T.42. The function $g(z)$, where

$$g(z) \equiv \int_{z_0}^{z} f(x)dx$$

is regular throughout R and is such that

$$g'(z) = f(z).$$

The principle of correspondence. Together with the power series $\Sigma_0^\infty a_{[r+n]}x^n$ we may associate the complex series $\Sigma_0^\infty \|a_{[r+n]}\| \xi^n$. If we denote the first by $f(x)$ and the second by $\|f\|(\xi)$, we write

$$f(x) \rightarrow \|f\|(\xi)$$

and read this as $\|f\|(\xi)$ corresponds to $f(x)$. The important properties associated with this correspondence are

I. $\|f(x)\| \leqq \|f\|(|\xi|)$ if $\|x\| \leqq |\xi|$.

II. The radius of uniform convergence ρ of $f(x)$ is at least equal to the radius of convergence ρ' of $\|f\|(\xi)$, i.e., $\rho \geqq \rho'$.

A power series such as $f(x)$ is completely characterized by one variable and a denumerable infinity of elements. Let us write

$$f(x) = g(a_{[r]}, a_{[r+1]}, \cdots ; x).$$

It is then clear that the corresponding function is to be written

$$\|f\|(\xi) = g(\|a_{[r]}\|, \|a_{[r+1]}\|, \cdots ; \xi)$$

where $g(\cdots)$ is the same function in both cases, in the sense that addition and multiplication between vectors is carried over into addition and multiplication between the numbers that correspond to these vectors.

Let us consider two power series that we express as above in

the form

$$(1)\qquad \begin{matrix} g_1(a_{[r]},\ a_{[r+1]},\ \cdots\ ;\ x) \\ g_2(b_{[s]},\ b_{[s+1]},\ \cdots\ ;\ x) \end{matrix}$$

and their corresponding power series

$$(2)\qquad \begin{matrix} g_1(\|a_{[r]}\|,\ \|a_{[r+1]}\|,\ \cdots\ ;\ \xi) \\ g_2(\|b_{[s]}\|,\ \|b_{[s+1]}\|,\ \cdots\ ;\ \xi). \end{matrix}$$

It is supposed, naturally, that $g_1(\ \cdots\ )$ and $g_2(\ \cdots\ )$ do not necessarily lie in the same space. Now if a third power series $h(x)$ is formed from $g_1(\ \cdots\ )$ and $g_2(\ \cdots\ )$ by means of the postulated operations of addition and multiplication among their elements (this, of course, includes forming the derivative and integral), so that $h(x)$ may be written as

$$(3)\qquad h(a_{[r]},\ a_{[r+1]},\ \cdots\ ;\ b_{[s]},\ b_{[s+1]},\ \cdots\ ;\ x),$$

the principle of correspondence asserts that by means of the analogous operations in the number system there exists a complex power series with positive real coefficients equal to the function

$$(4)\qquad h'\|a_{[r]}\|,\ \|a_{[r+1]}\|,\ \cdots\ ;\ \|b_{[s]}\|,\ \|b_{[s+1]}\|,\ \cdots\ ;\ \xi)$$

which has the properties I and II, and which, therefore, corresponds to (3). The fact that I and II hold between (4) and (3), as well as between (2) and (1) is a direct consequence of the inequalities that appear in P.12, P.13, and P.21.

Implicit functions. The equation $y=f(x)$ is said to give y explicitly in terms of x, supposing, of course, that $f(x)$ is a clearly defined assertion that establishes the functional correspondence between x and y by means of operations upon x alone. When a variable y is defined unambiguously as a function of x, but not in the explicit form $y=f(x)$ it is said to be defined *implicitly*.

The implicit functions which we consider are those which involve only the postulated operations of addition, multiplication, and the limit process, but more particularly in a manner such that the explicit functions which do appear in the defining relations, which may be algebraic, differential, or integral equations, are all regular functions. In that case if the problem is to determine y as an explicit function of x in the neighborhood of some point, say the origin, we set

$$y = \sum_{0}^{\infty} b_{[r+n]} x^n \tag{5}$$

where the coefficients are undetermined and r is appropriately chosen. This is substituted into the defining equation, which may then be reduced to a power series, equated to zero, and whose coefficients are, therefore, equivalent to nullifying elements. In general this yields an infinite set of recurrence formulas which are sufficient to determine the coefficients of (5) in terms of those that are known. It only remains to show that the radius of uniform convergence of (5) is greater than zero, and it is here that the principle of correspondence plays its most important role; for since the defining equation is made up of regular functions, which we assume to be finite in number, or else reducible to a finite set, the unknown function y is of the type (3). But on account of property II we are assured that whenever the corresponding function (4) exists in some neighborhood of a given point the same is true of (3). Thus, in order to derive theorems on implicit functions for the abstract variable, it is only necessary to refer to the analogous theorems in the theory of the complex variable, and whenever the process there is such a one as described above, involving only addition, multiplication, differentiation, and integration, the theorem for the abstract variable is equally valid.

The problem of inversion is of fundamental interest in the theory of implicit functions. Suppose we are given a power series $\Sigma_0^{\infty} a_{[r+n]} x^n$ and the equation

$$y = \sum_{0}^{\infty} a_{[r+n]} x^n. \tag{6}$$

The problem of the functional dependence of x on y may be solved under certain conditions by assuming this dependence to be expressed by an equation

$$x = \sum_{0}^{\infty} b_{[r+m]} y^m \tag{7}$$

where $b_{[r+m]}$ is an undetermined coefficient. Assuming $x \epsilon E_{[1]}$ the only value of r which will satisfy (6) and (7) is 1, so that the functions considered are on $E_{[1]}$ to $E_{[1]}$. Without restricting the general case, we can set $a_{[1]} = 0$, and, consequently, $b_{[1]} \neq 0$.

We have, on substitution

$$y = \sum_{1}^{\infty} a_{[1+n]} \left\{ \sum_{1}^{\infty} b_{[1+n]} y^m \right\}^n$$

and on comparing coefficients, after multiplying out, it is seen that the coefficients of (6) must satisfy the recurrence formulas

$$b_{[2]} a_{[2]} = 1_{[2]}{}^*$$
$$b_{[3]} a_{[2]} + a_{[3]} b_{[2]}^2 = 0. \tag{8}$$

Each equation of this set is of the form $b_{[n]} a_{[2]} = c_{[n]}$, where $a_{[2]}$ and $c_{[n]}$ are known. Let us write $d_{[2]} = 1_{[2]} - a_{[2]}$; then from the method of successive substitution it is seen that the solution is, formally,

$$b_{[n]} = c_{[n]} \sum_{0}^{\infty} d_{[2]}^m$$

which otherwise may be verified directly. However, in accordance with an explanation already given, the symbolic product which constitutes the right hand member of the foregoing equation has a meaning only if the factors are multiplicable. By reference to the properties of multiplicable vectors that are given on p. 9a, it can be readily seen that each coefficient $b_{[n]}$ is well-defined if the aggregate of coefficients $a_{[1]}, a_{[2]}, \cdots$ are all multiplicable among themselves and if the infinite series converges. The series certainly converges uniformly for $\|d_{[2]}\| = \|1_{[2]} - a_{[2]}\| < 1$, but if this inequality is not satisfied, what then may be said concerning a solution?

Let us consider the function $\Sigma_0^{\infty} x_{[2]}{}^m$, from which, by continuation, we obtain an extended regular function. This latter, which we denote by $(1 - x_{[2]})^{-1}$, is well-defined and regular everywhere within its domain of existence except at its singular points. Because of this, and the fact that functional relations persist in continuation, we may write

$$b_{[n]} = c_{[n]} (a_{[2]})^{-1}$$

in place of the last equation, and assert that this is certainly a solution if $a_{[2]}$ is not a singular point of $(x_{[2]})^{-1}$. On the other hand if $a_{[2]}$ is a singular point of the function, a solution may or may not exist, as we know from the theory of linear functional equations.

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* Here $1_{[2]}$ is that element of $E_{[2]}$ which satisfies the equation $1_{[2]} y = y$ for all y. It is easily seen with the aid of P.22 that $1_{[2]}$ is symmetric. It is also clear $1_{[2]} a_{[2]} = a_{[2]} 1_{[2]} = a_{[2]}$ whatever $a_{[2]}$ may be.

Let us suppose that the set of equations (8) have been solved. They are identical in form with those given, say, in *Theory of Infinite Series* by Bromwitch, p. 156, 2nd ed., in the inversion of complex power series, where it is shown that the inverted power series has a positive radius of convergence. Hence by the correspondence principle the same, at least, is true of (7). The result may be stated as in the following theorem.

T.43. If $f(x)$ is a regular function on $E_{[1]}$ to $E_{[1]}$ such that all its derivatives at $x=x_0$ form a class of mutually multiplicable vectors, and such that $f'(x_0)$ is not a singular point of $\{f'(x)\}^{-1}$ then there exists an inverse function which is regular in a neighborhood of x_0.

Differential Equations. First, it is seen that the extension of the notion of regularity to functions of several variables can be easily made. Thus, we say that $f(x, y)$ is regular in the (ρ_1, ρ_2) neighborhood of (x_0, y_0) if

$$f(x, y) = \sum_0^\infty a_{[r+n+m]}(x - x_0)^n(y - y_0)^m,$$

and if the series converges uniformly for $\|x-x_0\| < \rho_1 < 0$ and $\|y-y_0\| < \rho_2 > 0$. The general properties of regular functions may be carried over; in particular, that of continued differentiability.

We consider the differential equation

$$\frac{dy}{dx} = f(x, y)$$

where $f(x, y)$ is a regular function on $E_{[1]}{}^2$ to $E_{[2]}$ in a neighborhood of (x_0, y_0). If the coefficients in the representative power series are multiplicable among themselves, it may then be asserted that the differential equation admits a unique solution $y=y(x)$ on $E_{[1]}$ to $E_{[1]}$, which is regular in a neighborhood of x_0, and which reduces to y_0 for $x=x_0$. The method of proof is simple. We assume a Taylor's series expression for $y(x)$, and with the aid of T.13 and T.14 we calculate the successive derivatives of $y(x)$. For example, we have for $y''(x)$

$$y''(x) = \sum_0^\infty a_{[r+n+m]}\{n(x - x_0)^{n-1}(y - y_0)^m + m(x - x_0)^n(y - y_0)^{m-1}y'(x)\}$$

where $y'(x)$ is obtained from the given equation, where the multiplication indicated is made in order from left to right. The successive derivatives are calculated in the same manner. From the correspondence we may conclude that the power series thus obtained converges uniformly for

$$\|x\| < \rho_1(1 - e^{-\rho_2/2\mu\rho_1}),$$

where μ is the least upper bound of $\|f(x, y)\|$ within the (ρ_1, ρ_2) neighborhood of (x_0, y_0).

In a similar manner it is possible to prove an existence theorem for the homogeneous linear differential equation of order n, whose coefficients are regular functions with derivatives appropriately multiplicable.

Note: Abstract polynomials have been defined by Gateaux* and Frechet,† but since the definition of Frechet has a restricted applicability, not being valid for the complex number system, we shall discuss only that of Gateaux. It is as follows:

$P(x)$ is said to be a polynomial of degree n if

(1) It is continuous for every x.

(2) $P(\lambda x - \mu y)$ is a polynomial of degree n the complex numbers λ and μ for all distinct pairs x, y and λ, μ.

In addition, $P(x)$ is said to be a homogeneous polynomial of degree n if $P(\lambda x) = \lambda^n P(x)$ for every pair λ, x. Now it was shown by Gateaux that every polynomial may be decomposed into a finite sum of homogeneous polynomials, and it may also be shown that the polar form of a homogeneous polynomial $P_n(x)$ of degree n is a continuous, homogeneous, linear function $Q(x_1, x_2, \cdots, x_n)$ of the n increments $x_1, x_2, \cdots, x_n$ such that

$$P_n(x) = Q(x, x, \cdots, x).$$

Moreover, the polar form is symmetric in each pair of its arguments, and hence, by T.9, may be expressed in a form $a_{[n]}x_1x_2 \cdots x_n$ where $a_{[n]}$ is some symmetric element which belongs to $E_{[n]}$. It follows that

$$P_n(x) = a_{[n]}x^n$$

for every x.

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* *Fonctions d'une infinite de variables independantes; avec note de Paul Levy, Soc. Math. de France Bull.*, v. XLVII, 1919.

† *Les polynomes abstraits, Journal de Math.*, 9e serie, v. II, 1929.

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VICTOR T. ALLEN

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A consideration of the Geological Aspects of Evolution involves the entire geologic record of nearly two billion years as well as the long uncertain stages preceding the known eras. From this great store house of information it is necessary to select with care the topics which are to be briefly treated and the episodes which are to be regarded as typical illustrations. A brief sketch of this inviting subject may be presented under four headings: (1) the origin of the earth, (2) the origin of life, (3) evolution and the geologic record, (4) the Quaternary or The Age of Man.

The origin of the earth. The first problem of evolution with which the geologist is concerned is the origin of the earth. This problem is astronomical as well as geological, for the evolution of the earth can not be divorced from that of the component members of our solar system. The earth is one of nine planets, which rotate about and in the same direction as the sun. In 1796

the astronomer Laplace proposed the nebular hypothesis of the earth's origin, which was probably suggested by the rings of Saturn. According to this hypothesis the solar system was originally a vast nebula of highly heated gas, extending beyond the orbit of the outermost planet and rotating in the same direction as the planets now rotate. As this nebula, which was more than five billion miles in extent, lost heat, it contracted. Due to contraction, the speed of rotation increased and resulted in flattening at the poles and a bulging at the equator. As further contraction continued, the speed of rotation increased until the centrifugal force at the equator of the spheroid was equal to the force of gravity and a ring of particles was left behind. The process continued until successive rings were formed and the central mass became the sun. Each ring rotated as such for a time and then broke up to form a planet and its satellites. According to this hypothesis the earth was first a globe of highly heated gas, then it became liquid and later a crust formed over the liquid interior. For more than one hundred years this was accepted as the most satisfactory explanation of the origin of the earth. During this time unexplainable objections accumulated and in 1905 Chamberlin and Moulton offered as a substitute the planetesimal hypothesis. In this hypothesis it is assumed that our solar system originated as a spiral nebula composed of finely divided solid or liquid material. Each knot-like mass in the arms of the spiral nebula grew by capture of material into a planet or a satellite, and the central mass became the sun. At first the nucleus of the earth was too small to retain an atmosphere, but later the heavier gases accumulated to form the initial atmosphere and when saturation occurred the condensed water vapors formed the oceans. The planetesimal hypothesis removed many of the difficulties which were unexplainable under the Laplacian hypothesis, but also it introduced new problems. In the effort to solve these problems, modifications of the current theories and new ones were advanced. Among the hypotheses which have received wide publicity is the Tidal Theory of Jeans and Jeffreys. But, the same objection applies to each, namely, it is not complete in itself, for it does not explain the original matter of the universe from which the planets evolved. Therefore, the

question of the origin of the nebulae or stars that are taken as the starting point in these hypotheses remains unanswered. To the thinking individual, this is satisfactorily explained as the work of an eternal God, who knows no beginning or end.

The origin of life. To the advocates of materialistic evolution, the origin of life is their most perplexing problem. There is scarcely a scientist today who believes that life originated on some distant heavenly body and immigrated to the earth during an early stage of its history. Complex compounds such as constitute living matter can exist only within a narrow range of temperatures. It is unlikely that such compounds could withstand the journey through space, or the probable early high temperature and atmosphereless stages of earth history. The essential chemical constituents of living matter or protoplasm are among the earth's most common elements. Speculation has included the most likely place for the synthesis of protoplasm to take place. Some favor the surface waters of the ocean. Others consider that the pore space of sedimentary rocks would contain the proper concentration of required substances. But, spontaneous generation does not take place in nature, nor have inorganic substances been changed into living matter in the laboratory. Many non-Catholic scientists find the materialistic interpretation of life and the universe unsatisfactory. To me it seems reasonable that matter as well as the universe and life originated through the creative and conservative power of an omnipotent eternal God. Under this concept, evolution is a process, a method. And God has the power to utilize this method if He so wishes.

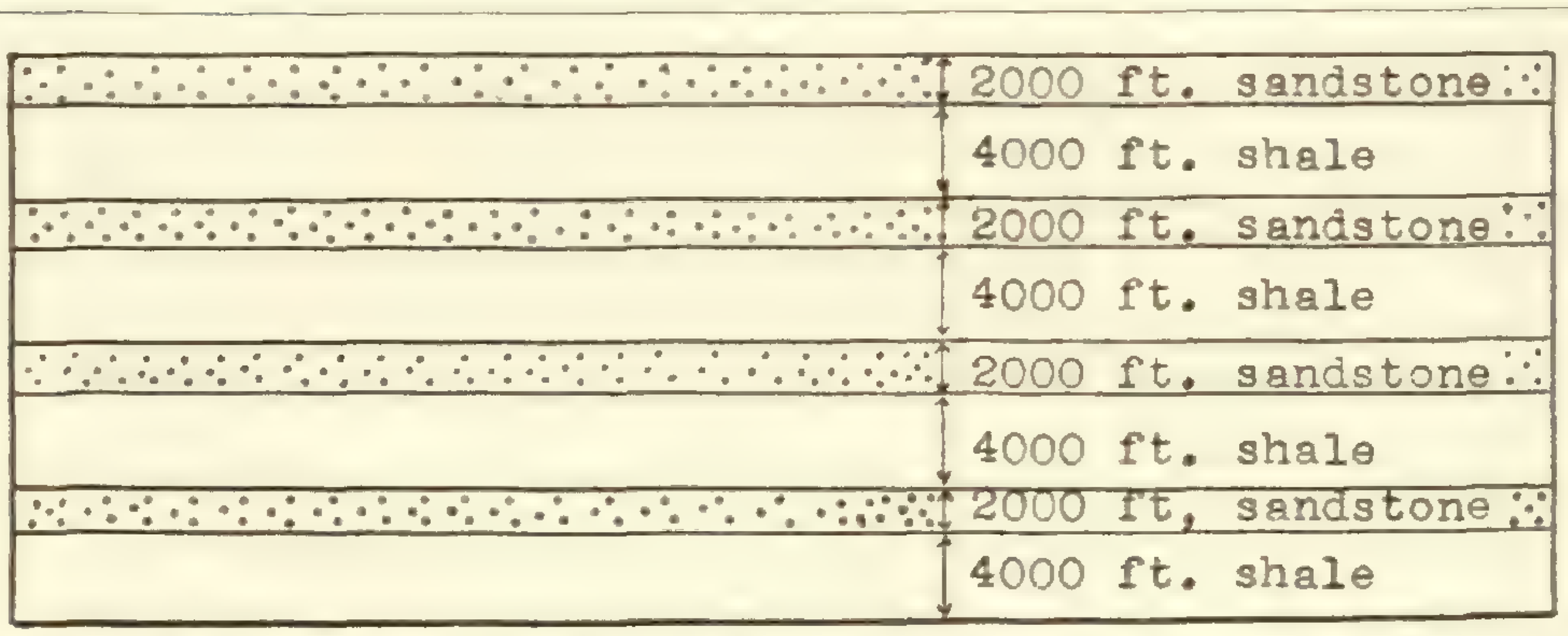
Evolution and the geologic record. The principle of evolution has been intimately interwoven with stratigraphic geology since William Smith in 1799 announced that the fossil assemblages of one geological formation differed from those above and below. Once the vertical range and sequence of fossils are established, the relative position of rocks can be determined by their fossil content. Superposition is the criterion of age. Any rock is considered younger than the one on which it rests, provided there is no structural evidence to the contrary, such as over-turning

ERA	PERIODS	LIFE	BEGAN	LASTED	KNOWN MAXIMUM THICKNESS OF SEDIMENTARY ROCK IN N. AMERICA
CENOZOIC (recent life)	Quaternary { Recent, Pleistocene	AGE OF MAN	1 million years ago	still continues	61,000 ft.
	Tertiary { Pliocene, Miocene, Oligocene, Eocene	AGE OF MAMMALS	60 million years ago	59 million years years	
MESOZOIC (intermediate life)	ROCKY MOUNTAIN CONSTRUCTION		EROSION INTERVAL		
	Cretaceous, Comanchian, Jurassic, Triassic	AGE OF REPTILES	170 million years ago	110 million years	86,000 ft.
PALEOZOIC (ancient life)	APPALACHIAN MT. CONSTRUCTION		EROSION INTERVAL		
	Permian, Pennsylvanian, Mississippian	AGE OF AMPHIBIANS	500 million years ago	330 million years	110,000 ft.
	Devonian, Silurian	AGE OF FISHES			
	Ordovician, Cambrian	AGE OF INVERTEBRATES			
	GRAND CANYON-KILLARNEY REVOLUTION		EROSION INTERVAL		
PROTEROZOIC (early life)		AGE OF PRIMITIVE FORMS OF LIFE	1,000 million years ago	500 million years	
	WORLD WIDE MT. CONSTRUCTION		EROSION INTERVAL		Total 257,000 ft. (about 50 miles) since beginning of Cambrian period.
ARCHEOZOIC (beginning life)			1,850 + million years ago	850 + million years	

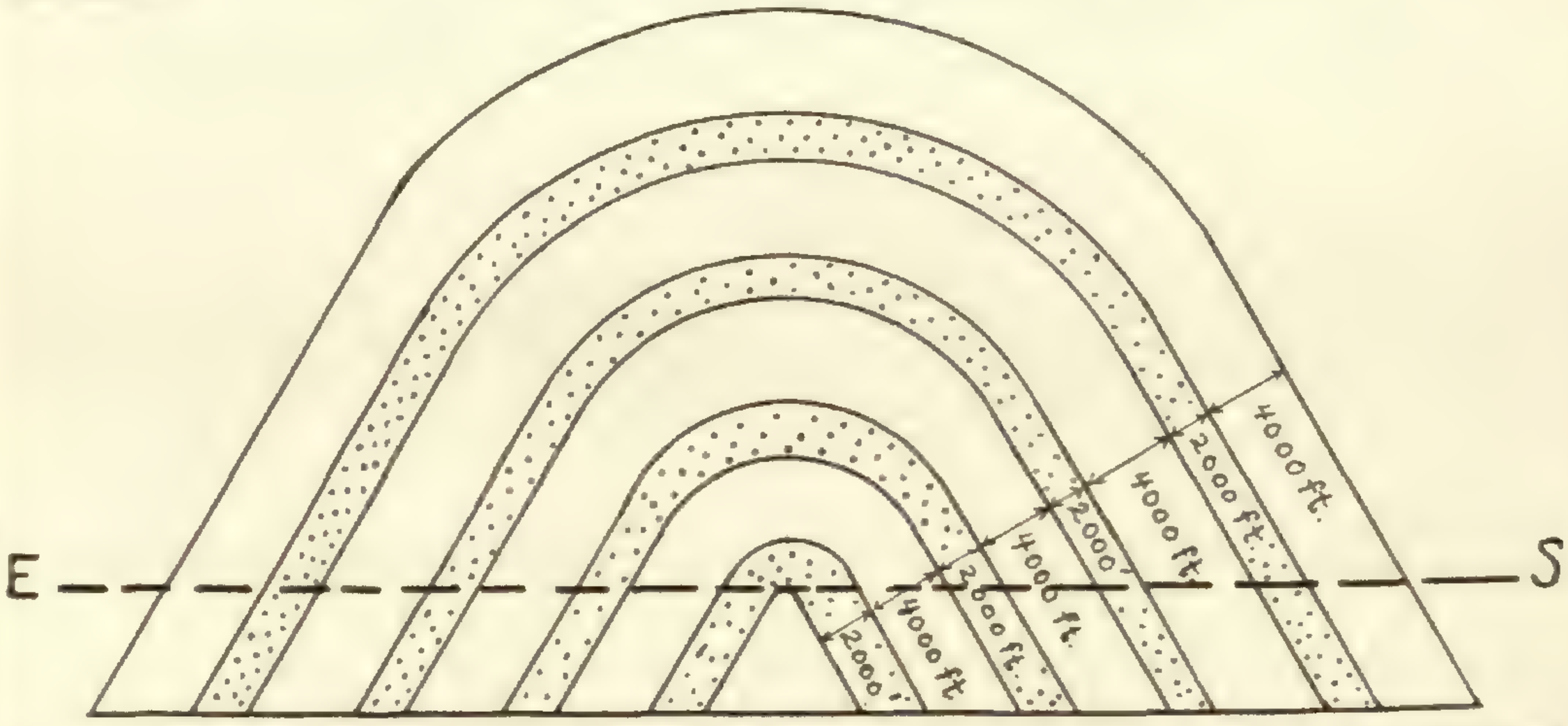
Table 1: Shows Eras and Periods of Geologic Time and the Appearance of Higher Types of Life with Advancing Time.

or thrust faulting. The rocks of the accessible part of the earth are divided into five major divisions or eras, which have been determined and named on the basis of the fossils contained in them (See table 1). The oldest rocks belong to the Archeozoic era, meaning the era of beginning of life. Archeozoic rocks are overlain by those of the Proterozoic era of early life and these may be traced upwards into rocks of the Paleozoic era of ancient life. Upon the Paleozoic strata rest the rocks of the Mesozoic era of intermediate life. At the top of the column are the rocks of the Cenozoic era of recent life. The eras are divided into periods which may be grouped together to indicate the highest forms of life during that interval. The nature of the first life preserved as fossils has long interested geologists. And yet uncertainty surrounds the earliest form, because Archeozoic rocks have everywhere been intensely altered by heat, pressure, and earth movement and because very likely the earliest forms of life were without hard parts and unsuited to preservation. A discovery in the Archeozoic of Minnesota has been described as blue-green algae, a unicelled plant. Everyone does not agree on the evidence, but in the Proterozoic rocks there is undisputed evidence of algae and animal life, of which the highest form has been interpreted as a fragment of a crustacean, an invertebrate belonging to the phylum, Arthropoda. In the lower Paleozoic, fossils belonging to every phylum except the Chordata are prolific, so that this period may be referred to as the Age of Invertebrates. As increasingly younger rocks are examined, higher types of life appear in the proper order, fish, amphibians, reptiles, mammals, man. This is suggestive of the evolution of more highly developed types with the passage of time. The geologist is frequently asked how many years have passed since certain forms first appeared. In an endeavor to answer these questions, the most reliable data available have been assembled as Table 1. The beginning of the Paleozoic era when only invertebrates lived is placed at five-hundred million years ago, the beginning of the Mesozoic era or Age of Reptiles at one-hundred-seventy million years ago, the beginning of the Tertiary or Age of Mammals at sixty million years ago, and the beginning of the Quaternary or Age of Man at one million

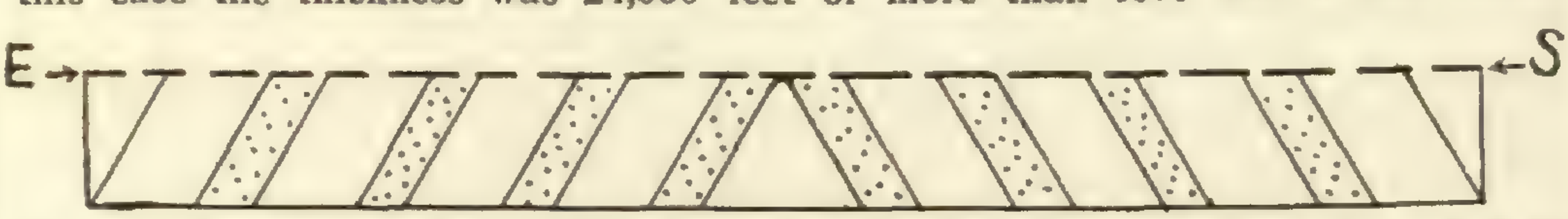
Figure 1.



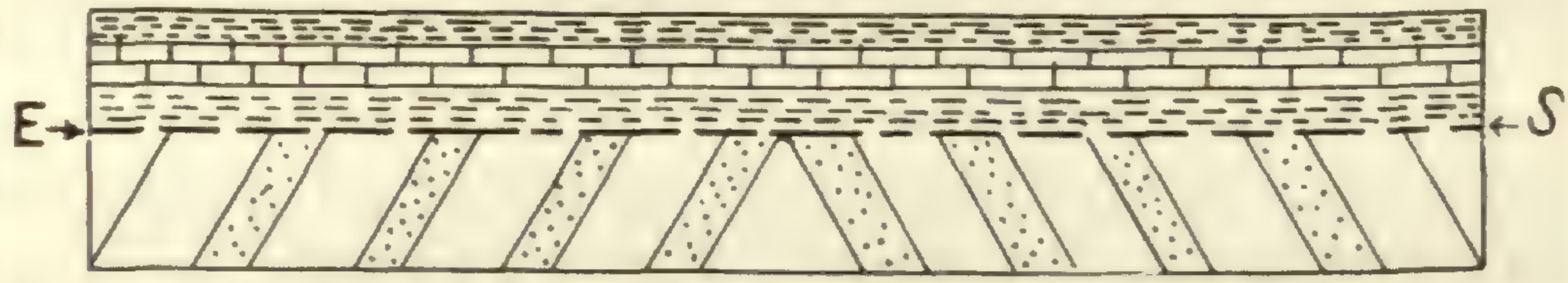
In stage 1 there was deposition of flat-lying sandstones and shales of uniform thickness.



In stage 2 these sediments were folded. The mountain structure so produced would be at least as high as the combined thickness of the folded rocks. In this case the thickness was 24,000 feet or more than four and a half miles.



In stage 3 erosion reduced the mountain to a level surface (the line E-S in stage 2). The part eroded can be calculated or reconstructed by measuring at any point the thickness of each affected formation perpendicular to its bedding. Erosion would be rapid at first, but later as the slopes became more gentle, it would progress slowly. Assuming an average rate of one foot every ten years, 240,000 years would be required to erode the 24,000 feet of strata removed.



In stage 4 flat-lying shales and limestones were deposited on the erosion surface E-S. At this locality the strata above the line E-S are separated from the underlying rocks, by a time interval which was long enough to allow the erosion of four and a half miles of sedimentary rock. For this interval 240,000 years would not be considered excessive by geologists. Several such unconformities are known in the geologic record.

Figure 1. **An unconformity is shown in stage 4 between the flat-lying shales and limestones above the line E-S and the tilted strata below the line E-S. It is evident that the horizontal sediments now above the line E-S were not present when the underlying sediments were tilted, for if they were, these also would have been tilted. This unconformable relationship was developed in the four stages above indicated.**

years ago. The next question which logically follows is, upon what are these estimates based? There are several methods but only two will be briefly touched upon here. One is based upon the known thickness of sedimentary rocks and the rate at which these are being deposited today. Unfortunately, the rate of sedimentation varies widely at different places. But even if we knew the average rate during the deposition of the known 50 miles of sedimentary rocks deposited since the beginning of Cambrian time, the figure so obtained would be a minimum. For, the rocks are separated at many places by unconformities or erosion intervals in which deposition of the products of erosion took place beyond the limits of the present continents and also by under-water breaks or diastems. Another method is known which proceeds at a constant rate without interference. Radioactive elements, such as uranium, disintegrate and give off particles at a rate which has been determined and yield as an end-product, lead with an atomic weight different from ordinary lead. Eight stages have been established in the radium disintegration series, in which elements of lower atomic weights are formed at a measured rate. Thus, uranium with an atomic weight of 238 is progressively changed by the loss of positively charged helium atoms each having an atomic weight of 4 until there is formed a stable product, uranium lead with an atomic weight of 206. Knowing the uranium-lead ratio and the rate at which atomic disintegration proceeds, it is possible to determine the age of the mineral and the geologic formation in which it occurs. By this method the oldest rock, which is of Archeozoic age, is 1,850,000,000 years old, and those of the Upper Cambrian which is the first period of abundant invertebrates, are 450,000,000 years old. Allowing time for the deposition of the Middle and Lower Cambrian, the beginning of the Paleozoic is estimated at 500,000,000 years ago.

Some of the great erosion intervals occurred at the close of the eras and were caused by mountain-making disturbances, which folded and tilted the originally flat-lying sediments. These movements changed the distribution of land and sea and the life of the sea and the land was affected by each new disturbance. The close

Figure 2.

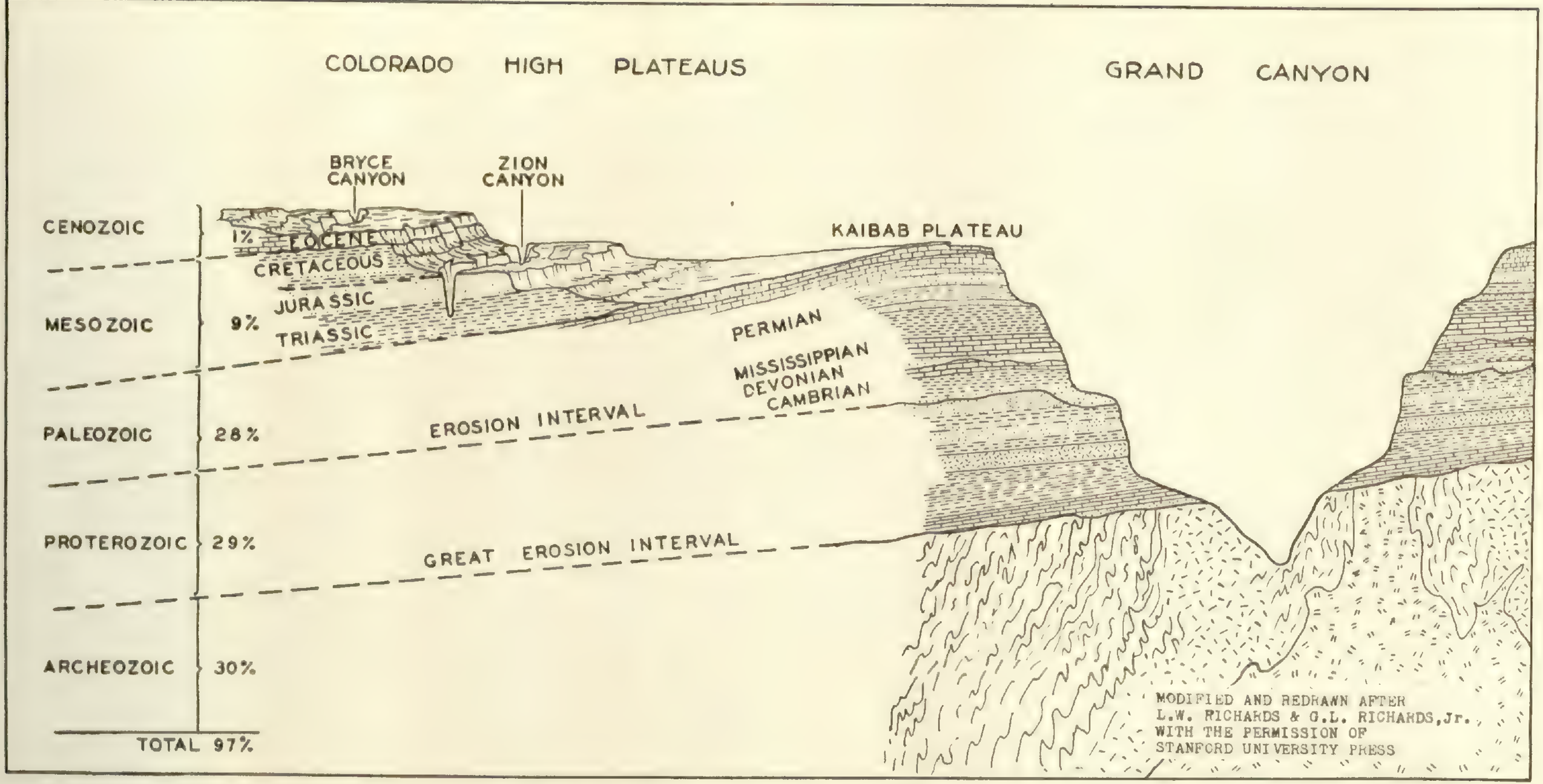


Figure 2: As one climbs up the north rim of the Grand Canyon of the Colorado River in Arizona and journeys across the Kaibab plateau to Zion and Bryce Canyons in Utah, successively younger rocks are encountered which belong to each era of the earth's history. In the combined exposures, nearly 97 percent of the geologic record is represented.

of the Paleozoic era brought with it the rise of the Appalachian Mountains. It has been estimated that only three percent of the Paleozoic forms of life survived and lived on into the Mesozoic era. The birth of the Rocky Mountains at the close of the Mesozoic was accompanied by widespread destruction of reptilian life. Some of the intervals of erosion were so long that mountains, miles high were eroded to a flat surface before sedimentation was resumed on the truncated edges of the mountain structure (See figure 1). These intervals allowed time for the changes in life recorded in the overlying sediments. In figures 2 and 3 there are shown rocks belonging to each era of the earth's history separated by erosion intervals.. The distances involved are so great that it is impossible to show in a single photograph the entire sequence. However, by carefully tracing the sequence of rocks of one region into another, it is possible to determine correctly the stratigraphic position of the formations and to construct a geologic cross-section showing their structural relations. This has been done in figure 2 for the region of the Grand Canyon and the Colorado High Plateaus, in which nearly ninety-seven percent of the geologic record is represented. In the Mississippi Valley the rocks of each successively younger period overlap from north to south like shingles on a roof (Figure 3).

To mention the appearance of each higher type of life with advancing time gives only part of the story. Each early representative of a class was primitive and generally its span of life was short so that it can be used as a guide fossil to the period in which it lived. The highest developed fish of the Age of Fishes differed from any fish living today, in being covered with bony plates instead of scales and in the structure of its tail. The primitive amphibian, Eryops, is limited to the Upper Paleozoic. A Stegocephalian Amphibian was the first animal to possess a skeleton having four limbs, each terminating in five digits. This skeletal plan, which is common to all the higher vertebrates, originated in Upper Paleozoic time. During the Age of Reptiles the dinosaurs and related forms dominated the land, the sea and the air, but all of these including the largest land animal that ever lived,

Figure 3.

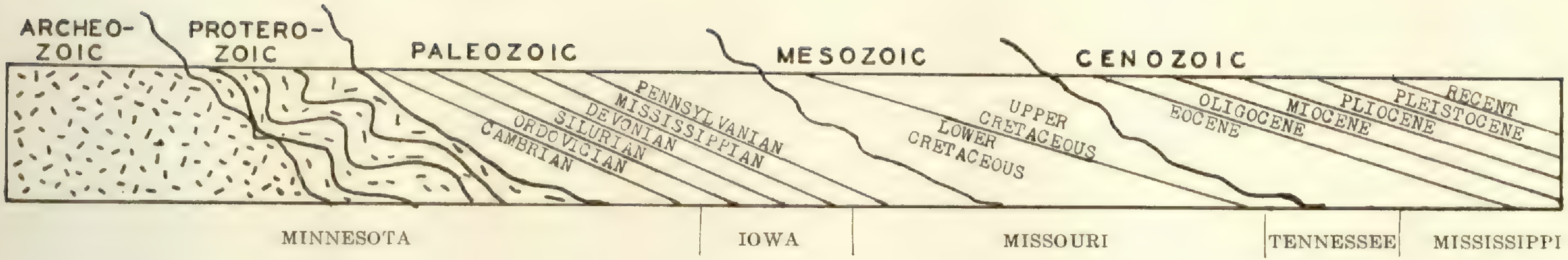


Figure 3: **Generalized section showing age of rocks in the Mississippi Valley from Minnesota to the Gulf of Mexico.**

disappeared with the close of the Mesozoic. In the Cenozoic there were long lines of animals that are more familiar to us, the mammals, including such forms as the horse, camel, dog, and elephant.

Many invertebrates, too, changed in the course of geologic time. To take a single case, we shall compare the cephalopods of the Paleozoic with those of the Mesozoic. But first, let us examine figure 2 which combines the region of the Grand Canyon with that of the Colorado High Plateaus, and so make certain that the rocks of the Mesozoic actually overlie those of the Paleozoic and therefore consist of younger strata. The lower Paleozoic cephalopods all have straight or slightly curved suture lines, marking the divisions between the chambers. In shells of Upper Paleozoic cephalopods, the sutures are decidedly curved. The ammonite cephalopods, limited to the Mesozoic, have such intricately winding sets of sutures that you can easily distinguish the Mesozoic forms from the Paleozoic. If you examine all the sutures of some ammonites, you will find that the sutures become increasingly complex with growth, so that the life history of the individual recapitulates the history of the cephalopods during 400,000,000 years.

The Quaternary or The Age of Man. The Quaternary is often referred to as the Age of Man. It is not the purpose of the writer to discuss the antiquity of man's body by an evaluation of the known fossil remains, as this belongs in the field of paleontology, but rather to attempt to bring out by a compilation the relation of the fossils and the implements to the geologic deposits containing them (See table 2). The Quaternary is divided into the Pleistocene which is the Glacial Period, and the Recent, which includes the present time. The estimates of most authorities place the beginning of the Pleistocene between 500,000 and 1,000,000 years ago. During the Pleistocene there were four major advances of the ice, which have been recognized independently in Europe and North America and separate names were given for each stage on the two continents (See Table 2). Each advance of the ice was followed by a long interglacial period during which the ice melted and the climate as shown by the fauna and flora

GEOLOGICAL DIVISIONS		FOSSIL MAN	ANIMAL LIFE*	CULTURE
				IRON
				BRONZE
				COPPER
	RECENT Beginning of recession of last ice sheet 13,500 to 25,000 years ago	HOMO SAPIENS: MODERN RACES; CHANCELADE; CRO-MAGNON; GRIMALDI	DOMESTICATED ANIMALS Reindeer Woolly elephant Woolly rhinoceros* etc.	NEOLITHIC: SWISS LAKE-DWELLERS 7000 years ago AZILIAN 12,000 years ago
PLEISTOCENE	IV WÜRM GLACIAL STAGE (Iowa-Wisconsin)		Reindeer Elephas primigenius Woolly rhinoceros Musk Ox*	PALEOLITHIC: MAGDALENIAN SOLUTREAN AURIGNACIAN
PLEISTOCENE	THIRD INTERGLACIAL	NEANDERTHAL	Elephas antiquus Equus caballus Rhinoceros merckii*	MOUSTERIAN ACHEULEAN
PLEISTOCENE	III RISS GLACIAL STAGE (Illinoian)		Woolly rhinoceros Arctic fox Elephas primigenius*	CHELLEAN
PLEISTOCENE	SECOND INTERGLACIAL (Very Long)	EOANTHROPUS (?) SINANTHROPUS PEKINENSIS HEIDELBERG	Elephas Antiquus Saber-tooth tiger Rhinoceros, cave lion, bear, deer, bison*	PRE-CHELLEAN
PLEISTOCENE	II MINDEL GLACIAL STAGE (Kansan)			
PLEISTOCENE	FIRST INTERGLACIAL	PITHECANTHROPUS (?)	Hippopotamus Elephas trogontherii Equus stenonis*	
PLEISTOCENE	I GÜNZ GLACIAL STAGE (Nebraskan)		(*List not complete)	
Beginning of Pleistocene or Glacial period 500,000 to 1,000,000 years ago.				

Table 2: **Shows Divisions of the Quaternary and the Fossils and Cultures of the Glacial Stages.**

was warmer than at present. Evidence of the existence of man during the glacial period comes mainly from Europe, where fragments and skeletons of fossil man are associated with the bones of extinct animals and stone implements, which were covered by geological deposits. The first well-fashioned stone implements were shaped by chipping and belong to the Paleolithic culture. This culture was followed by the Neolithic in which stone implements were polished. The Paleolithic culture of Europe is divided into the Lower Paleolithic consisting of the Pre-Chellean, Chellean, Acheulean and Mousterian, and the Upper Paleolithic consisting of the Aurignacian, Solutrean and Magdalenian epochs. The order or sequence of these cultural epochs has been established by finding the implements buried in strata one on top of another. Along the Somme River in France implements belonging to the Chellean, Acheulean and Mousterian stages of Lower Paleolithic culture occur below the recent loess which contains implements of Upper Paleolithic culture. At some localities the geologic horizon containing stone implements may also contain bones of extinct animals. As the vertical range of cultures and animals is fixed with reference to the glacial and interglacial stages there has gradually developed a three-fold method of dating the rarer finds of human remains, for human bones may be embedded in a geologic deposit of a known glacial stage, or these may be associated with the bones of animals which did not live beyond a certain glacial stage, or there may be present implements belonging to a culture limited to a known glacial stage. In Germany the Heidelberg jaw was found eighty feet below the surface and below the loess of two glacial periods. Stone implements are absent, but the sands of the Mauer containing the jaw have yielded a large fauna which has helped to fix the age of the jaw as not younger than the second interglacial period. Some writers have been criticized for attaching too much significance to a single jaw, but a half dozen jaws of Sinanthropus Pekinesis all show the same chinless feature. Besides the jaws and teeth, two good skulls and fragments of other bones of Sinanthropus were found embedded in travertine in a cave near Peking, China. In an adjoining cave stone and bone implements and evidence of the use of fire were discovered along with jaw and skull fragments, but

the assignment of Sinanthropus to the early Pleistocene is on the basis of the animal bones occurring in the same travertine deposits composed of calcium carbonate.

The geologist who is accustomed to think in terms of geologic events and processes is satisfied with dating a discovery with reference to a glacial or interglacial stage, but when the same statement is made to the average individual, he generally asks, "How many years ago was that?" As nature has the feminine characteristic of jealously guarding her exact age, it is best to start the answer to this question at a point of reference on which scientists agree, namely that man witnessed the last glaciation. The implements of Lower Paleolithic culture were employed by intelligent individuals before the close of the glacial period. The best known race of this period is the Neanderthal of which no less than seventy representatives including seven nearly complete skeletons have been found. It is evident that some of the cave-dwellers saw the great ice-sheets come and go, so that if we can date the beginning of the recession of the last ice sheet, we are also setting a minimum for the age of man. The most accurate method of measuring glacial time is the varve method of De Geer. It is known that water from melting glaciers during the summer deposits in lakes a coarse layer of light colored sediment, and during the winter a thin layer of dark colored sediment. The annual layer of light and dark material is termed a varve. By counting the varves DeGeer and Linden found that 13,500 years have elapsed since the ice uncovered Central Scandia. But, during the last invasion the ice had extended southward across Germany and Poland. To allow time for the retreat of the ice from Poland to Central Scandia, the late Father Stephen Richarz, S.V.D., estimated another 5,500 years would be needed, or 19,000 years would be required for the entire retreat from Poland to the present limit of the ice sheet. As man existed when the ice advanced to northern Germany, additional time must be allowed for the advance of the ice to northern Germany. Assuming the conservative figure of 1 foot a day as the rate of movement of the glacier, it would require 11,000 years for the glacier to move the 750 miles from its place of origin in Scandinavia to northern

Germany. On this basis, Father Richarz concluded that the minimum figure for the existence of man is 19,000 years plus 11,000 years, which equals 30,000 years. Father Richarz regarded this figure as a minimum, for many authorities including Hugo Obermaier, Abbé Breuil, Father Teilhard de Chardin, S.J., G. Elliot

Figure 4.

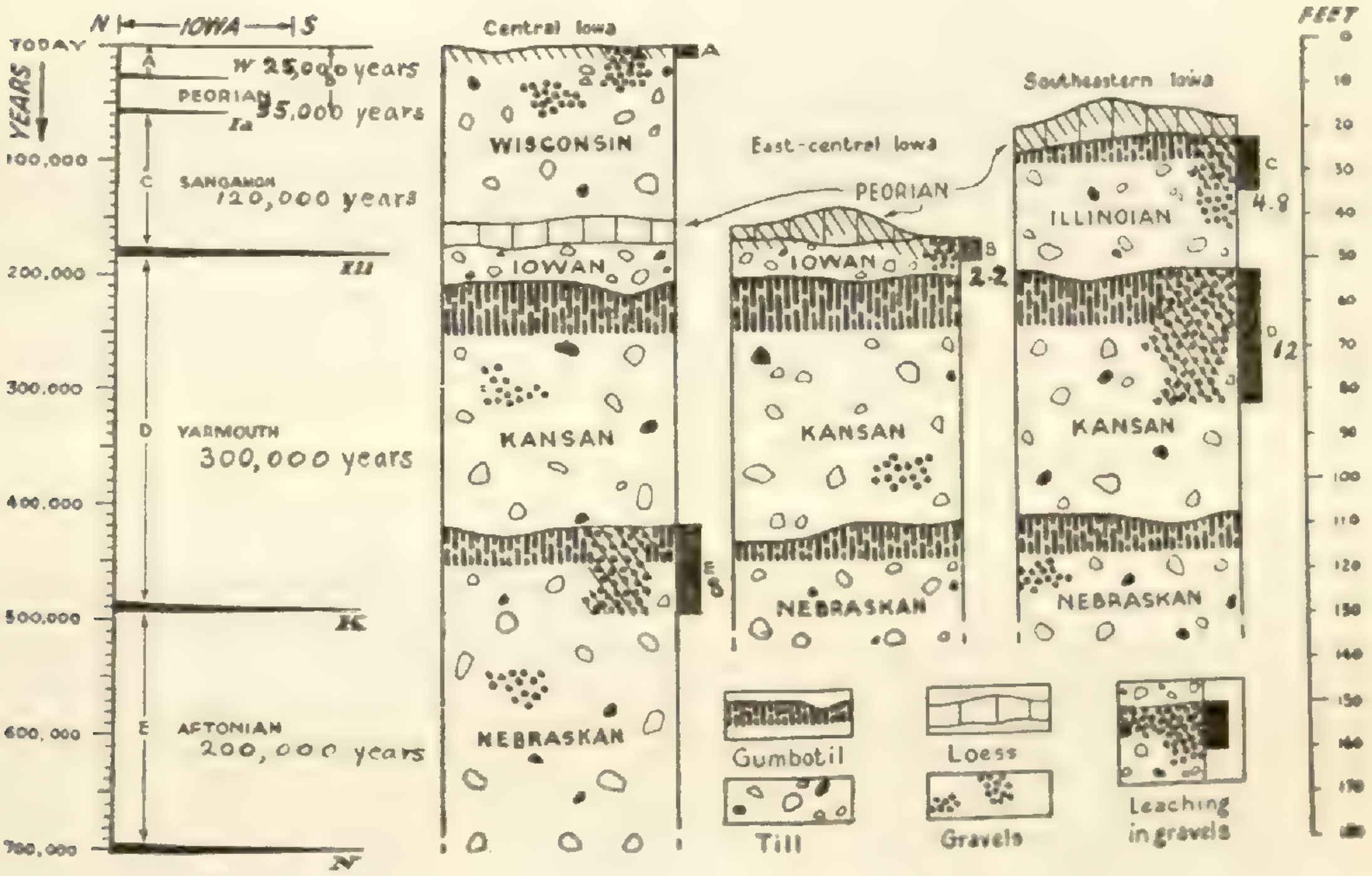


Figure 4: **Minimum Duration of Pleistocene Period in Iowa. After G. F. Kay. Based on relative depths of leaching in upland gravels. The diagram indicates relative depths of leaching of upland gravels in Iowa and the estimates of minimum duration of glacial and interglacial ages and of the Pleistocene Period as a whole.**

Smith and Henry F. Osborn consider that man existed during the earlier interglacial stages. As a consequence this figure must be increased many times, if it is to include the earliest record of fossil man.

Ernst Antevs, who used the varve method in North America, considers that the ice sheets disappeared from Europe and North America about the same time, due probably to a rise in temperature. R. A. Daly in his book, "The Changing World of the Ice Age" shares this idea and accepts Antev's figures for the rate of recession of the last ice sheet from North America. After a discussion with Antevs and Frank Leverett, George F. Kay decided that 25,000 years is the safest estimate that can be made of the interval since the last ice sheet (Late Wisconsin) began its retreat from Iowa. The evidence is conclusive that there were several stages of glaciation in Iowa, for glacial deposits are separated by erosion surfaces, weathered surfaces, peat formed from plant material, and loess, a wind deposit (Figure 4). The four stages here include, Nebraskan, Kansan, Illinoian and Wisconsin which is made up of Iowan, and Early and Late Wisconsin (Figure 4).The most significant evidence is the weathering of the glacial deposits, for it affords a means of comparison of the length of the interglacial ages with the time elapsed since the retreat of the ice from Iowa. The deposits of the last glacial stage (Late Wisconsin) have been weathered to an average depth of two and a half feet since they were deposited, and to this interval has been assigned 25,000 years. The nature and the depth of weathering of the Iowan deposits are considered by Kay to have required 2.2 times as long, or 55,000 years (Figure 4). On the same basis, the weathering of the Illinoian till would take 4.8 times 25,000 years or 120,000 years, the weathering of the Kansan 12 times as long or 300,000 years and the weathering of the Nebraskan 8 times or 200,000 years. The combined duration of the interglacial ages would be 675,000 years. To this must be added the time required for the ice to advance to and retreat from Iowa during each of the stages. Kay assumes this took place at the rate of one mile in ten years and would require about 30,000 years more, giving a minimum duration of about 700,000 years for the Pleistocene of Iowa. This estimate falls about midway between the 500,000 and 1,000,000 years favored by most scientists as the duration of the glacial period. The work of Kay is

valuable in that it affords another method on which may be based estimates of the age of the deposits of older fossil man.

In conclusion, the geologic record supports the doctrine of evolution, in that it reveals the appearance of progressively higher types of life with advancing time, but the origin of the earth, of life, and the earliest stages of man's existence are enveloped in mystery.

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Meetings are held on the second and fourth Wednesdays of each month at 8:15 P. M. in the Auditorium of Wilson Hall, Washington University. Each member is notified of all meetings.

Many of the early volumes of the Transactions of the Academy of Science of St. Louis are still available. Volumes I to V consisted of four numbers each, containing numerous articles by Shumard, Wizlizenus, Swallow, Prout, Engelmann, Riley and others. Many of these are still available at $2.00 per number or $4.00 per double number. Beginning with Volume VI each number was issued separately and usually contained only a single article. The following list contains a few of the important numbers still available:

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VOLUME XXIX, No. 5

The Pre-Cambrian Structure of Missouri

HOWARD B. GRAVES, JR.

Issued January 31, 1938

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The Pre-Cambrian Structure of Missouri

Howard B. Graves, Jr.

Introduction

General Statement

Little previous work has been done on the structure of the pre-Cambrian rocks of Missouri. Inasmuch as faults in the Paleozoic rocks extend to the pre-Cambrian area on the east and north, it seemed probable that they might extend into the pre-Cambrian. It also seemed likely that some of the Paleozoic structures were due to movement along pre-Cambrian fault planes. This investigation was therefore undertaken with the intention of locating as many pre-Cambrian structures as possible and relating them to later structures. It was hoped that the structures found could be correlated with those in pre-Cambrian rocks of other regions and something learned of the nature of the forces which produced them.

Discussion of the pre-Cambrian of Missouri is based on field work done in the summers of 1933 to 1936. The strike of joints was determined in nearly 100 localities in the St. Francois Mountains by measuring from 10 to 100 joints in a given locality, the number depending on their regularity. The geology of several small areas was mapped in order to determine the relation of the distribution of various rocks to structures. The discussion of structures occurring in rocks younger than pre-Cambrian is based largely on the work of others as recorded in the literature.

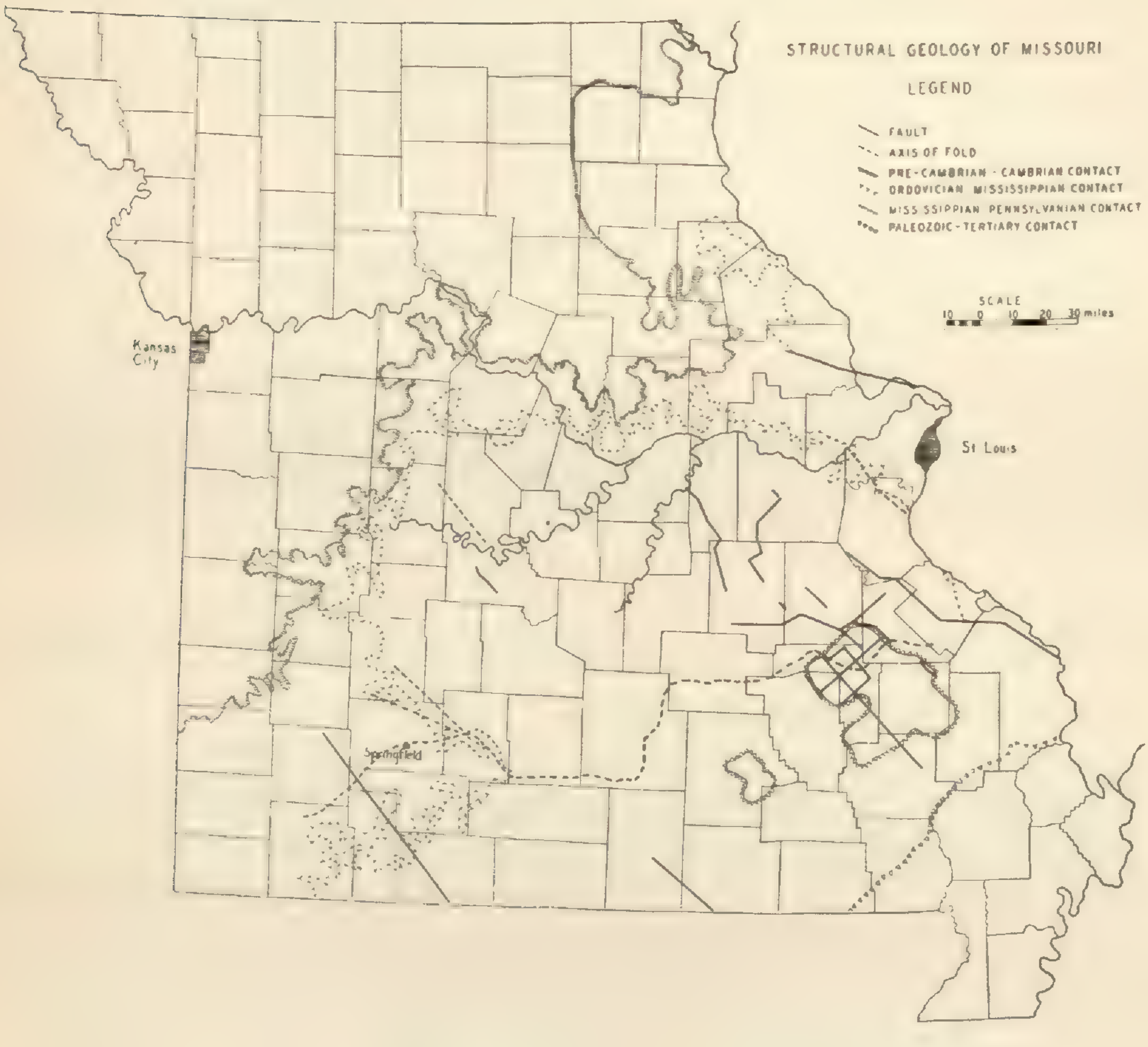


PLATE I. STRUCTURAL GEOLOGY OF MISSOURI

Location of Area Studied

Missouri lies in the two physiographic provinces known as the Interior Plains and the Interior Highlands (15). The northern part of the state is within the Dissected Till plains while the southern part is within the Ozark Plateau. The northern end of the Gulf Embayment touches the southeastern corner of the state. The intermediate location of the state is reflected in its structural geology for most structures are parallel to those of the region to the southwest but some structural trends are also characterisitc of the eastern and southern states.

The pre-Cambrian rocks are exposed chiefly in the St. Francois Mountains region, located at the apex of the Ozark Dome, (Plate I) where they outcrop over an area about 35 miles long by 25 wide in Iron, Madison, St. Francois, Reynolds, and Wayne counties. Southwest of the St. Francois Mountains, in Shannon County, there is an area of pre-Cambrian rocks which is smaller in extent than that of the St. Francois Mountains. Small areas of pre-Cambrian rocks are found outside of these two main regions in Ste. Genevieve, Camden, Crawford, and Carter counties.

Geology of the Pre-Cambrian Areas

General

The distribution of the pre-Cambrian rocks is shown on Plate II which is compiled from the geologic maps of the Potosi, Edgehill, Eminence, Cardareva, Iron Mountain, Mine La Motte, and Bonneterre quadrangles, Ste. Genevieve County, and the Crystalline rocks of Missouri, all published by the Missouri Geological Survey, and from field observation. The rocks include intrusive and extrusive types and pyroclastics. Early writers (23) referred to all the extrusive rocks as porphyry and later writers have used the term rhyolite but these terms are not suitable because, although practically all the rocks are acidic, some of them are not porphyritic and some are not rhyolites. Tolman (46)

therefore suggested the use of the term felsite as the most suitable general term for these and for intrusive rocks of similar type.

The extrusive rocks include flows of acid to moderately basic felsites. Intruded into them are masses of granite and granite porphyry. Some of the felsites are also intrusives and there are small bosses and sills of diabase as well as basic dikes.

The age of the igneous rocks is known to be pre-Cambrian in most cases, but masses of igneous rocks not seen in contact with Paleozoic sedimentary rocks could be of later age. Dikes in Ste. Genevieve County cut Cambrian sediments but these dikes are of different composition from any of the rocks of the main St. Francois Mountains region. It is probable that, with the exception of these few basic dikes, all the exposed igneous rocks of the state are pre-Cambrian. Though the pre-Cambrian of Missouri has not been correlated with that of any other region, the lack of metamorphism suggests that the rocks may belong to the Algonkian rather than an earlier age.

Physiography

Topograhy. The topography in the pre-Cambrian area is of interest because of its possible relation to structure. It is also of importance in explaining the scattered distribution of the outcrops. The topography at the beginning of the Cambrian period must have been very rugged. Most of the present stream courses in the St. Francois Mountains are in pre-Cambrian valleys partly filled with Cambrian sedimentary rocks. In some cases valleys are filled to a depth of nearly 1,000 feet with sedimentary rocks and the felsite hills rise 500 feet or more above this level, giving a relief of over 1,500 feet on the pre-Cambrian surface. Additional evidence that the stream valleys are pre-Cambrian is shown in the fact that the Cambrian sediments are inclined towards the center of the valleys because of initial dip (4).

Differential weathering and erosion. In the central part of the St. Francois Mountains the hills are composed of igneous rocks while the valleys are floored with sedimentary rocks. Around the outskirts of the area there are hills of sedimentary rock which are chert covered. These are not as steep as the igneous knobs for the slope depends partly on the angle of repose of the chert. On topographic maps the igneous knobs may be distinguished by a much greater regularity in the contours than is seen in hills of sedimentary rocks.

As weathering in the igneous rocks is controlled by joint planes, there is considerable difference in the forms assumed by the granite and felsite which are jointed to a different degree. The wide spacing of joints in much of the granite causes it to weather into large boulders which reach their maximum development at Graniteville. These are due to weathering along horizontal as well as vertical joints thus causing the boulders to resemble erratics although they are actually in place. The felsite, due to the close spacing of the joints, is seldom seen in large boulders but weathers into small, angular blocks. Near the mouth of the Little St. Francois River there are chimneys of felsite 15 feet square, which are formed by weathering along vertical joint planes. These evidently owe their length to lack of horizontal jointing.

Not all of the differences in weathering are due to jointing. Because of the diversity in texture, the felsite tends to weather with angular corners while the granite is usually rounded. Granite hills are usually low and rounded while the felsite hills are higher and often conical. Granite is usually seen outcropping from top to bottom of the hills with its surface parallel to the slope of the hill. Felsite, on the other hand, is seen as talus near the bottom of a hill with an occasional outcrop on the side. Near the top of the felsite knobs there is usually a ring of outcrops surrounding the hill while the top is usually rather flat and with few outcrops.

Angularity is marked in the felsite weathering, not only in residual boulders but also in cliffs which frequently have ver-

tical faces and sharp angles due to intersecting joint planes. This is well displayed at Johnson Shut-in in the Edgehill quadrangle (11). As the felsites vary considerably in texture, the forms taken on weathering also vary, gradations being seen between the angular shape of the typical felsite and the rounded form of granite.

Basic dikes weather into small, rounded boulders with a rough surface which is easily recognized. In many cases the dikes are represented only by boulders in the soil. Dake (11) assumed that the presence of basic boulders where there were no outcrops indicated that the diabase weathered more rapidly than the felsite. This might however, be taken to mean that the diabase was so resistant that boulders remained after all the felsite had disintegrated.

An example of a dike that has resisted erosion to a greater extent than the felsite is the one in the SW. ¼ sec. 3, T. 33 N., R. 4E. which is shown on the Iron Mountain quadrangle (53). It is surrounded by sedimentary rocks because it projected above the surface on which they were deposited. At Silver Mine, a basic dike forms a trench in the granite, indicating that it was less resistant to erosion than the granite. Most dike rocks are very hard and dense, although thin sections show the ferromagnesian minerals to be highly altered in most cases. It is possible that the dikes are more resistant to mechanical weathering and less resistant to chemical weathering than the felsite so that their elevation depends on which process has been dominant. The fact that jointing causes the dikes to break up into small blocks may also tend to increase the weathering of the dike rock.

Narrows occur where streams flowing on the sedimentary rocks cut down until they reach igneous knobs, and are known locally as shut-ins. These shut-ins are due to the fact that the igneous rocks are more resistant to erosion than the sedimentary rocks. Dake (11) describes a number of such shut-ins within the Edgehill quadrangle and others occur throughout the igneous area.

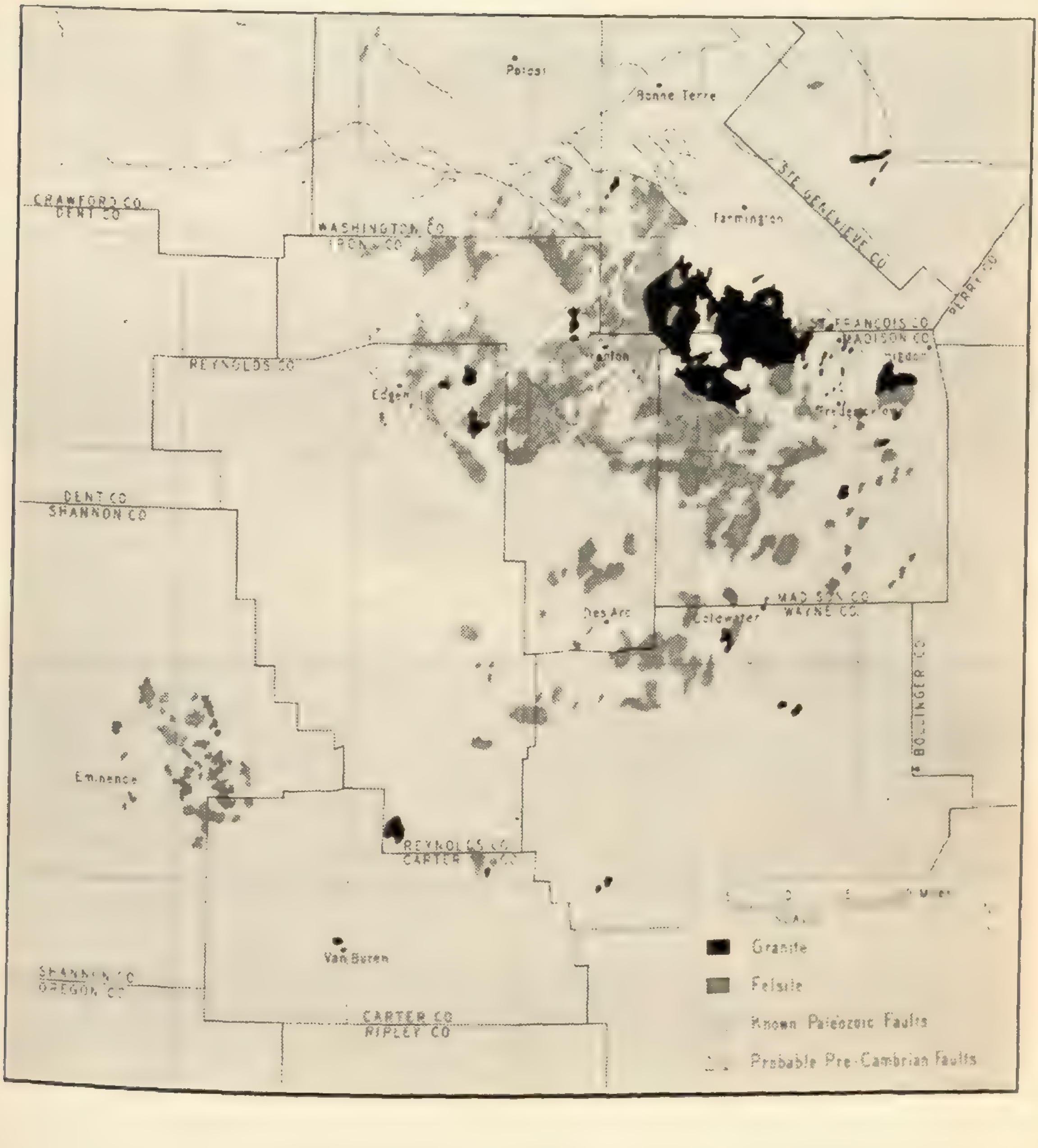


PLATE II. THE PRE-CAMBRIAN ROCKS OF MISSOURI

Pre-Cambrian surface under the Paleozoic. Not a great deal is known of the pre-Cambrian surface beneath the sedimentary rocks. However, the outcrops of igneous rocks around the borders of the Ozark region in Ste. Genevieve and Camden counties in Missouri, and in Mayes County, Oklahoma, indicate that the whole area is underlain by a plateau of Pre-Cambrian rocks. Though the topography of the exposed pre-Cambrian rocks is very rugged, there is no evidence that the surface under the Paleozoic formations is equally rugged. Pre-Cambrian exposures are due to uplifted blocks which were formed during the pre-Cambrian. Erosion at the end of the period must have been more active in these uplifted areas than in the comparatively level areas surrounding them.

A number of wells in the Missouri Ozarks reach the pre-Cambrian. At Sedalia, quartzite is encountered at 1,600 feet, which is probably pre-Cambrian as the St. Peter sandstone is reached at 360 feet in the same well. At Lebanon, pre-Cambrian quartzite occurs at 985 feet, according to Shephard(38), but Gould (18) gives the depth as 1,900 feet. The former is probably correct as the base of the St. Peter is at the surface and it is seldom more than 1,200 feet above the pre-Cambrian in the Ozark region. At Sullivan, the pre-Cambrian has been reported at 1,200 feet, and near Rolla, at 1,700 feet(51). At Pomona, in Howell County, granite was reached at a depth of 2,500 feet. Near the western boundary of the state at Carthage, the pre-Cambrian lies at a depth of 1,950 feet below the surface.

Off the Ozark Dome, wells reach the pre-Cambrian along the Missouri River Valley. In Jackson County, northeast of Kansas City, Missouri, granite is encountered at a depth of 2,400 feet with the bottom of the well in rocks of Silurian age. The pre-Cambrian here is probably lower than in any other part of the state due to a synclinal structure in the northwest portion of the state.

Petrology

Granite. The largest body of granite outcrops in an area 15 miles long by 10 wide, in the contiguous portions of the Iron Mountain and Mine La Motte quadrangles. It has considerable

variations in texture and color and accessory mineral studies (47) show the borders of the main mass to consist of a number of different types. Scattered outcrops of granite in the eastern part of the area covered by the Mine La Motte quadrangle and in the Higdon quadrangle may belong to the main body. There are three types of granite in Ste. Genevieve County on Jonca and Pickle creeks, one of which corresponds to that of the main mass.

Along the southern border of the main mass there is a medium-grained, red granite which is distinguished from the rest of the granite by its heavy mineral assemblage (47). It is also characterized by the presence of a number of dikes striking northeast which are not found within the main mass. The name Silver Mine granite will be used in referring to this rock.

The granite at Graniteville is red and coarse-grained; much of it is porphyritic; pegmatitic phases occur in the southern part of the area. No basic dikes are found in this body of granite. Near Cornwall, a very coarse granite is cut by a basic dike two feet wide which strikes N. 55° W. Coarse-grained granite also outcrops southwest of Coldwater where it is cut by a basic dike 20 feet wide which strikes N. 45° W. (45). Tolman and Koch (47) classified the granite near Van Buren and near Coldwater with the Graniteville granite on the basis of heavy mineral assemblages. They also found considerable amounts of the same type granite within the main granite area. Granites which appear to be thus related to the granites occurring at Graniteville will be called Graniteville granite.

Fine-grained, red granite, here called the Ironton granite, occurs in two outcrops west of Ironton. Near Hogan there are two outcrops of granite which is rather fine-grained and may belong to the same period of intrusion as that at Ironton. Tolman and Koch (47) described a fine-grained granite, which occurs between Fredericktown and Knoblick, which may also belong to the same generation of granite as that at Ironton.

A brownish or dark-colored granite occurs near Skrainka Hill, in the Mine La Motte quadrangle and has been described

by Denham (12). It is similar in accessory minerals to a granite in Ste. Genevieve County (47).

Gray granite cuts the red along Jonca Creek in Ste. Genevieve County (49) and is found in the vicinity of Syenite.

Granite porphyry. Granite porphyry, outcropping in the Edgehill quadrangle, differs from granite in texture and it has a somewhat lighter color than most of the granite. According to Tarr (43) the area mapped by Haworth on the south side of Mount Devon as granite, is granite porphyry. Tarr (43) also mentioned granite porphyry as occurring near the Cornwall granite outcrop. The hill east of Wolf Mountain in the granite area which is mapped as felsite by Haworth is also granite porphyry according to Tarr (43). Haworth (53) describes a granite porphyry in the northern end of sec. 11, T. 33 N., R. 5 E. Probably other areas of granite porphyry are present and have been mapped either as granite or felsite.

Felsite. Tarr (43) mentions an intrusive, black felsite near the Cornwall outcrop. The writer found evidence of a body of intrusive felsite crossing Stouts Creek, west of Ironton and probably detailed mapping would show the intrusive nature of a number of other bodies of felsite. The highly porphyritic character of some of the felsite is suggestive of an intrusive.

Basic rocks. Small, basic dikes are quite abundant in the areas covered by the Iron Mountain and Mine La Motte quadrangle but are not common in other pre-Cambrian outcrops. A few occur in the Edgehill quadrangle and have been reported as occurring in the Higdon, Coldwater, and Des Arc quadrangles. According to Bridge(3), none occur in the Shannon County area. Ste. Genevieve County has a number of basic dikes in the granite(49). Large masses of basic rock are found in the eastern half of the Edgehill quadrangle and the southern half of the Mine La Motte quadrangle.

Composition of the dike rocks is not as variable as texture. The dike rocks in the Edgehill quadrangle are composed of gabbro which may contain olivine in addition to plagioclase and

augite (11). The diabase at Tin Mountain contains much glassy material(28). Most of the dikes in the Mine La Motte quadrangle as described by Keyes, are olivine diabase, but one west of Silver Mine contains phenocrysts of quartz and orthoclase(28) and is therefore not a diabase. According to Haworth (53), the dikes of the Iron Mountain quadrangle are mostly olivine diabase which varies in texture from glassy to as coarse-grained as the granite. Most of the dikes are pophyritic, with phenocrysts as large as two inches in diameter in the case of the dike on the north side of Mount Devon.

Extrusive rocks. The extrusive felsites are mostly rhyolite with some andesite, dacite and trachyte. Most of the rocks are porphyritic and many show flow structures. Flow breccias are found at a number of localities. The extrusives vary in color, occurring mostly in shades of red although there are also black, gray, green, brown and purple tones.

Evidence that these rocks are surface flows is seen in the following facts: pyroclastics are associated with them; columnar jointing is seen at Hughes Mountain; there are large amounts of flow breccias; a few examples of amygdules occur; and much of the felsite is apparently devitrified volcanic glass.

Pyroclastics. Pyroclastics, consisting of tuffs and agglomerates, occur in small bodies interbedded with the felsites. The largest outcrop is near the top of Pilot Knob where the tuffs contain ripple marks and have been highly altered by pre-Cambrian iron-bearing solutions. Above the tuff there is a thick bed of agglomerate. A good exposure of tuff is seen along Highway 21 on the south slope of Tip Top and both tuff and agglomerate occur on the East fork of the Black River at Johnson Shut-in (11). Agglomerate is found in large quantity at the intersection of Highway 61 and the Saco road. There are also a large number of outcrops of material, which may be an agglomerate, in the northwestern quarter of the Coldwater quadrangle. Tuff is found as float throughout the St. Francois Mountains and has been reported by Bridge (3) from Shannon County.

The tuff is fine-grained and firmly cemented, generally pink or buff in color, with some green varieties, and some contains concretions, which appear to be made up of siderite. Though the tuff is usually stratified and sometimes finely laminated, the agglomerate is never stratified.

Sedimentary rocks. There are no undoubted pre-Cambrian sedimentary rocks in Missouri, although the pyroclastics were once considered to be metamorphosed sediments. Dake(11) mentions a deposit near Redmondville which might be a conglomerate although it is probably an agglomerate. Boulders of quartzite are found in considerable number in the Tom Sauk Mountain area, but they may be merely a phase of the Lamotte sandstone. Drill-holes in the more northern parts of the state pass through a considerable thickness of pink quartzite lying above the igneous rocks which may be metamorphosed sandstone of pre-Cambrian age. The drill-hole at Raytown(38) in Jackson County, penetrates a black mica schist which might be a metamorphosed shale. A drill-hole in Jasper County, at Carthage (38), is reported to have passed through felsite and then entered limestone.

Relative ages of pre-Cambrian rocks. The following table shows a suggested sequence of some pre-Cambrian events, the latest being listed first. There are no doubt many intrusions not included, and some of the events may not be in their right order, for the present work would have to be supplemented by detailed petrographic studies to more definitely determine the age relations of the various intrusions.

SEQUENCE OF PRE-CAMBRIAN EVENTS

Mineralization—Silver Mine and region southwest of Coldwater.
Intrusion of basic dikes—in granite near Coldwater.
Intrusion of gray granite—Ste. Genevieve County and Mine La Motte quadrangle.
Intrusion of Graniteville granite—at Graniteville, Cornwall, southwest of Coldwater, and within main granite area.
Intrusion of black felsite—at Cornwall.

Intrusion of granite porphyry—on the Edgehill, Mine La Motte, and Higdon quadrangles.

Iron deposits formed—at Pilot Knob, Iron Mountain, Shephard Mountain, Cedar Hill, Shut-in Mountain, and Buford Mountain.

Intrusion of fine-grained red granite—east of Ironton and west of Hogan.

Intrusion of red felsite—east of Ironton.

Faulting—Iron, Munger, and Hogan faults.

Intrusion of basic dikes—main dikes of Iron Mountain and Mine La Motte quadrangles.

Intrusion of Silver Mine granite—along southern border of main mass of granite.

Intrusion of diabase—at Skrainka, Tin Mountain, and in the Edgehill quadrangle.

Intrusion of fine-grained brown granite—at Skrainka and Jonca Creek.

Extrusion of felsite—throughout the St. Francois Mountains and Shannon County areas.

Part of the evidence for the above sequence is based on structure and will be discussed more fully later. All of the intrusions are later than the felsites which they intrude. Denham (12) found evidence that the fine-grained, brown granite was intruded by the diabase. The relation of the diabase to the Silver Mine granite is not known but the Silver Mine granite is intruded by the basic dikes striking northeast and is therefore older.

The early basic dikes are probably earlier than the faulting inasmuch as the majority trend at right angles to it, while later dikes are parallel to it. Faulting preceded the intrusions east of Ironton, since they seem to parallel the fault surface. It is also earlier than the Graniteville granite because the granite lies across two faults and is not displaced. The intrusions east of Ironton consist of granite intruded into rhyolite which in turn is intruded into felsite. Both the granite and the intrusive rhyolite contain abundant specularite and pyrite. This suggests that the iron ores were introduced with the granite and intrusive

rhyolite, for the ores that have been worked on Shut-in Mountain are in the rhyolite intrusion. The granite at Graniteville contains no iron although it is on the fault which the iron solutions evidently followed. This indicates that the Graniteville granite was later than the iron and consequently later than the granite east of Ironton.

At the Cornwall granite area, Tarr (43) finds the following relationships. Granite porphyry is intruded into the felsites and dark green to black felsite is intruded into both the granite porphyry and the felsite country rock. Coarse-grained granite was intruded later as is indicated by the fact that both the black felsite and the granite porphyry have epidote developed in them by solutions from the granite. In addition, the granite porphyry contains inclusions of felsite but no inclusions of the granite. Haworth (23) mentions a dike trending northwest in the Cornwall granite, and, according to Tarr and Bryan(45), the coarse-grained granite southwest of Coldwater is intruded by a large, basic dike trending northwest. Other areas where the Graniteville granite is exposed have no basic dikes. The Graniteville granite has well developed joints striking northeast although it contains no dikes striking in this direction. The felsite and Silver Mine granite include many dikes striking northeast although joints striking northwest occur in both the felsite and granite. A possible explanation of the strike of the dikes is that the first basic magma came close enough to the surface so that dikes could form along the joint planes while the later basic intrusion was deep-seated and came to the surface only along fault planes. The first intrusion of basic dikes was in the northeast rather than in the northwest set of joints as the former set was opened by tension. The scarcity of northwest striking dikes is in accordance with the conception that they follow faults.

The gray granite intrudes the red granite on Jonca Creek and near Syenite. At both these localities the red granite resembles the Graniteville variety in heavy mineral assemblage (47). Mineralization at Silver Mine is probably the last recorded event in the pre-Cambrian. Tolman (46) considers this

mineralization to be quite late but still pre-Cambrian inasmuch as it must have occurred at considerable depths and therefore have taken place before the erosion at the end of the pre-Cambrian and beginning of the Cambrian. Mineralization in the granite southwest of Coldwater is of a lower temperature type but may belong to the same period as that at Silver Mine. If it does, the mineralization may have been later than any of the granitic intrusions so far recognized. If the Silver Mine mineralization is of older age than that near Coldwater, it may be related to the Graniteville granite as it is younger than the granite at Silver Mine.

Description of Structures

Pre-Cambrian

Primary structures. Haworth believed that the granite was only a deeper phase of the felsite and it followed that the granite was continuous under the felsite throughout the whole region. While the intrusive nature of the granite is now generally recognized, it is still thought by some to be continuous beneath the felsite with the exposures merely cupolas on the top of a batholith. Relations to structure, however, indicate that generally each area must be considered as a separate instrusion.

The large igneous mass of the Central Granite area is apparently a stock. While the granite within the area varies considerably, it may all be part of the same intrusion and probably is of the same age as the Graniteville granite. The Silver Mine granite, which is older than the Graniteville, outcrops only along the southern boundary of the main granite area and probably is part of the country rock into which the younger granite was intruded.

The contact of the granite of the Central area with the felsite in the Iron Mountain quadrangle is relatively straight and independent of countour lines, indicating it is nearly vertical. The mass seems to be elongated in a northeast-southwest direction with its northeast and southwest sides parallel to the principal structural trends of the region. The northeast end of the granite body is buried under sedimentary rocks, but the granite

on Jonca Creek may be part of the same mass. The irregularity of the southeastern boundary of the mass is due to the fact that some of the granite along the boundary belongs to an intrusion earlier than the stock.

Haworth maps several hills in the granite area as being capped by rhyolite and the granite-rhyolite contact would represent the roof of the stock. According to Tarr (43), one hill mapped as porphyry is granite and another is granite porphyry and it is possible that the rock of most of these hills represents intrusions into the granite and the hills owe their relief to the superior resistance to erosion of this rock. The felsite on Knoblick Mountain and to the south and east may be a roof pendant.

The Graniteville granite mass is apparently a small boss elongated north and south. The granite south of Graniteville, on the Black River Road, is part of the same mass but is separated from it by a valley filled with sedimentary rocks. Support of the idea that the granite has the same width throughout its length that it has at the ends, is obtained from the fact that a drill-hole in the valley cuts felsite just outside of the line connecting the west boundaries of the two outcrops (53). The contact between granite and felsite on the hill east of Graniteville is vertical as is shown by the fact that it may be traced in an almost straight line from top to bottom of the hill in a southerly direction. Tarr (43) reported a sharp vertical contact at the southern granite exposure.

The two small intrusions of granite east of Ironton are probably connected, in which case the mass is more elongated than that of Graniteville and might be called a dike rather than a boss. With the granite is a dike or sill of felsite to be described later.

The granite porhyry in the Edgehill quadrangle(11) is apparently an intrusion into the felsite. It occurs in three separate outcrops, but these are separated by a valley filled with sedimentary rocks so that probably all three areas represent the same mass. The granite porphyry is quite irregular in out-

line indicating that the contacts are not vertical but dip steeply enough to be partly independent of the contour lines. This suggests that the outcrop of granite porphyry represents the top of a stock. This is also indicated by the area of felsite surrounded by granite porphyry on High Top Mountain which may be a roof pendant, since the strike of its contacts is independent of topography, thus showing that the body of felsite has vertical sides.

None of the granites have any visible internal structure such as parallelism of inequidimensional grains or oriented inclusions. Quarrymen claim that the granite splits easiest in one direction and hardest in another but, in every case, the easiest way is parallel to a set of joints and the ease of splitting may be due to incipient jointing. The lack of strongly developed, internal structure indicates intrusion by quiet stoping as any pressure should be reflected by the presence of internal structure in masses as small as those at Graniteville and east of Ironton.

The basic rocks are mostly in the form of dikes which cut the felsites and granites. At Tin Mountain and Skrainka Hill there are bosses of diabase. In Little Tom Sauk Mountain in the Edgehill quadrangle, the diabase is apparently in the form of a sill, for it outcrops on the slope of a hill roughly parallel to the contour lines (11).

Many of the extrusive rocks show flow structures which usually take the form of nearly horizontal sheets. In some cases, the sheeting is vertical but this is due to tilting rather than to initial position. Occasionally, the flow structures are schlieren, which are lenticular or spindle-shaped bodies. These are elongated in the direction of flow, indicating the contour of the surface over which the lava flowed.

As the tuffs are bedded, they show dip which may be initial or may be due to folding. An unconformity occurs in the tuff at Tip Top where a four inch bed of green tuff with a high angle of dip intersects the more gently dipping beds of brown tuff. This is probably a very local feature.

Folds. Because of the lack of bedding in the igneous rocks, it is difficult to recognize the presence of folding. It is probable that folding would be confined to regional tilting and to drag along fault planes since igneous rocks are brittle and easily fractured. Where tuffs are present, it is possible to measure the dip, and dip may also be determined where flow lines are present in the felsite. In the case where flow structures occur in sheets, the dip and strike can be measured just as in sedimentary rocks, but where flow structures take the form of schlieren it is necessary to measure the pitch of a number having different strikes in order to find the direction giving the maximum pitch. Dips may also be measured by mapping the contacts of different flows. This can be done only over small areas as there is too much variation within a flow to allow correlation of widely separated outcrops.

The regional dip seems to be to the southwest which is what would be expected because most of the felsite lies on the south and east flanks of the St. Francois Mountains. The general dip becomes steeper locally due in part to folding but mostly to drag along faults. Without doubt some of the dip in the felsite is caused by inclination of the surface on which the lava was poured out.

The dip in the pyroclastics at Pilot Knob is partly a result of synclinal structure and partly caused by tilting of the syncline (16). According to Tarr (43), intrusion of the granite has displaced the felsite causing vertical flow lines in some cases.

Joints(19). Joints in the granite include horizontal and vertical sets.

Horizontal sets, which are well displayed in the quarries at Graniteville, parallel the surface and disappear with depth suggesting that they owe their origin to relief of pressure on erosion of the overlying rock.

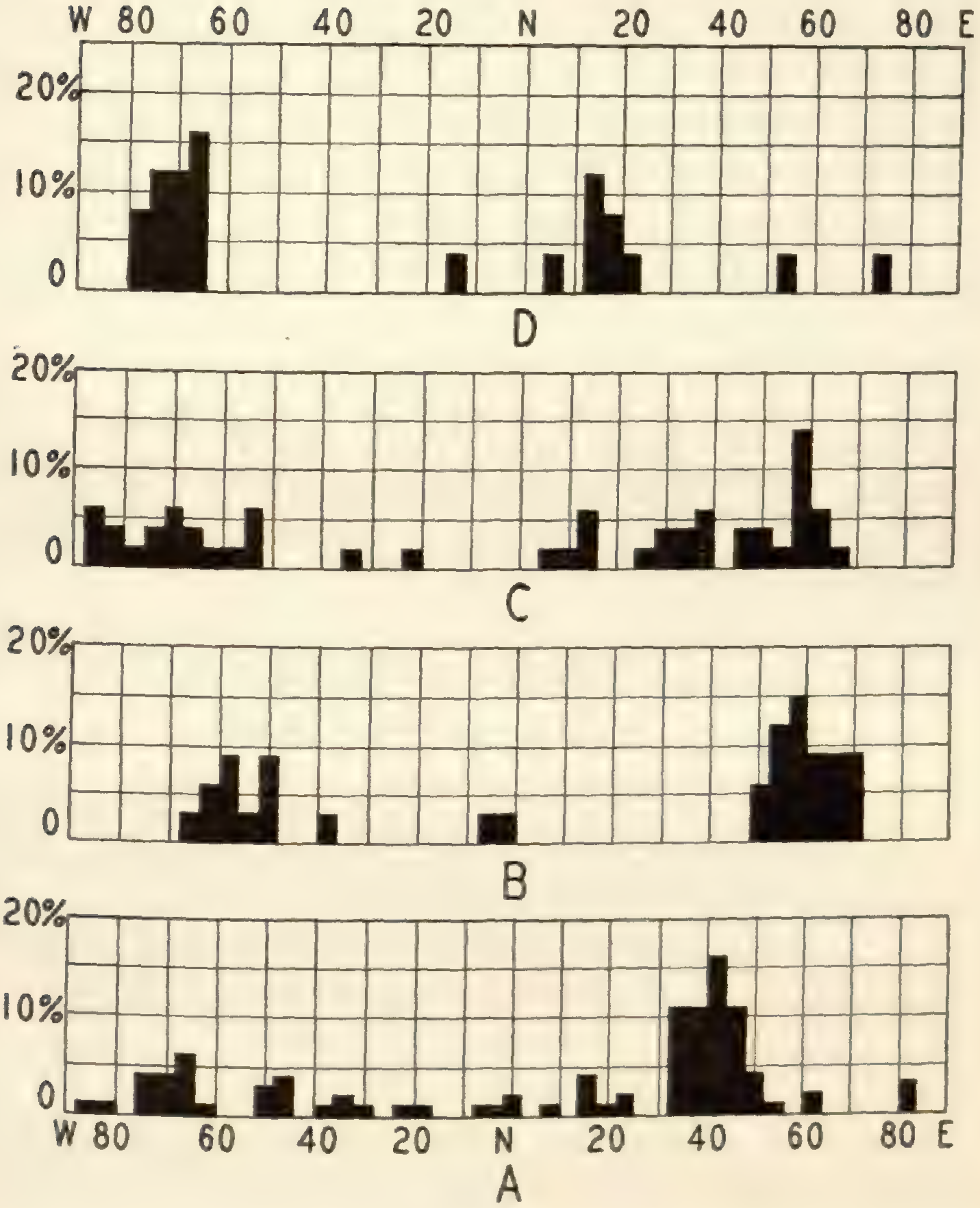


PLATE III. HISTOGRAMS OF JOINTS

A. Granite in Outcrop South of Graniteville
B. Granite at Graniteville
C. Granite at Wachita Mountain
D. Felsite at Hughes Mountain

The vertical joints fall into eight sets in which can be distinguished four systems, each consisting of two sets at right angles to each other. The sets strike about N.—S., E.—W., N. 40° E., N. 50° W., N. 65° W., N. 25° E., N. 65° E. and N. 25° W. In some localities one set will be dominant while in others a different set will be the most significant. Apparently there is no regular variation in dominance of the different sets with position within a body of granite, or between different bodies of granite.

Joints in the granite are much more regular than in the felsite but they are farther apart, averaging 20 feet between joint planes. Plate IIIA is a histogram based on 100 joints in the granite of the outcrop south of Graniteville, on the Black River road. The N. 40° E. set is the only one of any importance at this locality although the other sets are present. The granite at Graniteville (Plate IIIB) has the N. 65° E. set dominant with the N. 50° W. set also important and there are some N.—S. joints in both localities. While the histograms appear considerably different there is less difference apparent in the field. The western part of the southern granite area has the N. 65° W. joints best developed while the northern part of the Graniteville outcrop has the N. 40° E.

Plate IIIc shows a histogram based on 50 joints in the granite on Wachita Mountain in the Mine La Motte quadrangle. Here the dominant joints belong to the N. 60° E. group with minor jointing N. 70° W. and N. 40° E. The N. 70° W. group merges into the E.—W. and N. 50° W. groups.

Jointing in the felsite includes the same systems found in the granite but is much more frequent and irregular with joint planes only a few inches apart. This may, in part, be due to the fact that some of the joints have been formed by contraction on cooling. At Hughes Mountain in the Bonneterre quadrangle, columnar structure has been developed but even here the main systems may be distinguished. The columnar structure is partly due to contraction on cooling and suggests that the rock is a surface flow. This is also indicated by the abundance of flow lines.

The histogram shown in Plate IIID is based on 25 prominent joints at Hughes Mountain. In order to test the value of using prominent joints to determine the dominant directions of jointing, eight areas, each two feet square, were marked off and all joints within the areas sketched. Out of the 220 joints included, 63 belonged to the N. 70° W. set and 46 to the N. 15° E., which is about the same proportion seen in the histogram. As half of the joints belong to one set or the other, most of the jointing in this region must be tectonic rather than due to contraction on cooling.

Inasmuch as the geology of Stouts Creek Shut-in will be discussed in detail later, it is advisable to include a histogram of joints there. Plate IVE based on 45 joints in the dark felsite, shows the great abundance of N. 70° W. joints. This jointing closely resembles that of Hughes Mountain which is 18 miles to the north.

Joints in the tuffs are more regular than those in most of the felsites and are less closely spaced. The same systems of joints are seen in the tuffs as in the other igneous rocks (Plate IV F & G).

Dikes were intruded into joints and are therefore younger than the joints. While most of the basic dikes of the region forced their way into the N. 40° E. joints, others are found in various directions. The histogram of Plate IVH is based on 50 dikes shown on the Iron Mountain and Mine La Motte quadrangles or seen in the field. Apparently all of the joint systems were developed before the dikes were intruded. The fact that most of the dikes are in the northeast rather than the northwest and in the north—south rather than east—west directions suggests that north and northeast were the directions normal to regional tension which caused the joints to open.

Aplite dikes are found with various strikes showing no apparent system, thus suggesting that jointing originated after the intrusion of these dikes. One aplite dike on the Black River road in the granite, strikes N. 7° E. and is cut by closely spaced

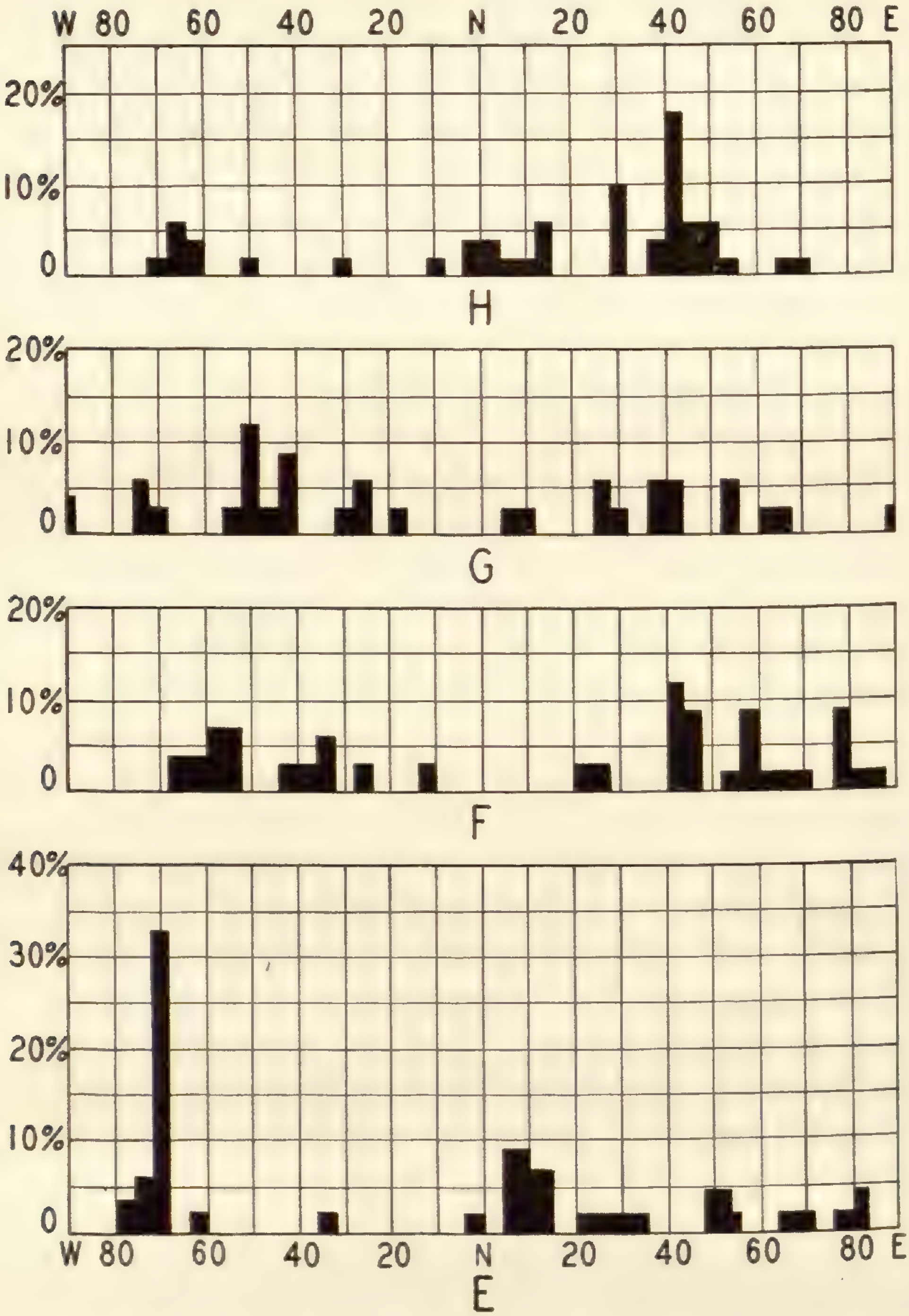


PLATE IV. HISTOGRAMS OF DIKES AND JOINTS

E. Dark Felsite at Stouts Creek Shut-in

F. Tuff on Tip Top

G. Fragmentals on Pilot Knob

H. Trend of Basic Dikes, Based on 50 Dikes

N. 40° E. and N. 50° W. joints, indicating that the dike is older than the jointing.

Faults. An alignment of topographic feautres extends from the northwest corner of the area covered by the Iron Mountain quadrangle to Grassy Mountain in the southeast corner, and may be seen in the boundaries of the igneous outcrops on Plate V. At the north end of the quadrangle, the alignment forms the east side of the Belleview Valley and the west side of Buford Mountain for a distance of about five miles. The line is broken for three-quarters of a mile by a side valley that extends toward Iron Mountain after which it continues again as a saddle across the hill north of Graniteville and passes through the valley between Pilot Knob and Shephard Mountain. South of Ironton, the valley widens and the alignment becomes indefinite. The writer believes that this topographic feature indicates the presence of a fault line scarp and proposes that the fault producing it be called the Ironton fault.

Another indication of the existence of faulting lies in the inclination of the felsite. Near the top of Shephard Mountain on the east side, the flow lines dip 12° in the direction S. 20° W., while down the slope the dip increases to 50°. Just across the valley, the tuff on Pilot Knob has a dip in the same direction. Southeast of Ironton at Stouts Creek shut-in, the felsites are vertical.

The difference in lithology on the two sides of the valley also suggests faulting, although it could be accounted for on the basis of dip. The felsite on Pilot Knob and Cedar Hill is red in color and includes some flow breccia. On the hill east of Graniteville, the felsite is red and very dense, shows no flow lines, and is not very porphyritic. On the other side of the valley, the felsite on Shephard Mountain is brownish to purple in color and shows very abundant and well-defined flow lines.

The location of the iron deposits of the Iron Mountain quadrangle suggests a structural line. Nason(33) describes veins of ore on Buford Mountain. No iron deposits occur in

the Graniteville area indicating the granite was intruded after the formation of the iron deposits. On Cedar Hill, iron ore has been mined from two veins which dip 20°, in the direction S. 45° W. which is similar to the dip in the pyroclastics at Pilot Knob (10). The ore is laminated and has a brecciated zone for a footwall suggesting that the ore solutions may have followed a thin bed of pyroclastics. Pilot Knob contains thicker pyroclastics with larger iron deposits. Crane (10) mentions a zone of shearing between the upper and lower ore beds at Pilot Knob, which consists of soft, grayish, micaceous material having a maximum thickness of three feet. The shearing zone may be due to a minor fault following a bedding plane in the pyroclastics. There are three vertical veins of iron ore striking northeast on Shephard Mountain to the west of the fault line, which are apparently in joints or faults, as they cut across the strike of the felsite. Iron ore occurs in nearly vertical veins east of Ironton on Shut-in Mountain but the felsite is also vertical so that the veins may follow bedding planes.

At the shut-in on Stouts Creek, east of Ironton, there is an excellent exposure of igneous rocks. Because of its accessibility and because of the variety of rocks exposed, this locality was chosen for detailed study. Plate VI shows the areal geology of this region. The rock exposed along Highway 70 through the shut-in and along Lake Kilarney is a black porphyry with red phenocrysts giving it a granitic appearance which suggests that it may be an intrusive but the abundant flow lines are more characteristic of an extrusive. At the shut-in the flow lines are vertical and strike N. 10° E., while a half mile north along the road the dip is 80° to the northwest, and the strike is N. 50° E. A half mile beyond this point the dip becomes 65° to the northwest and the strike N. 80° E.

On the top of the hill to the north of Highway 70, a purple flow breccia occurs and a small area of this same rock crosses Highway 70 and Stouts Creek at the east end of the shut-in. This isolated patch of breccia may indicate a depression on the top of the black and red porphyry into which the breccia flowed or it may be due to local folding or faulting. If

PLATE V. AREAL GEOLOGY OF IRON MOUNTAIN QUADRANGLE

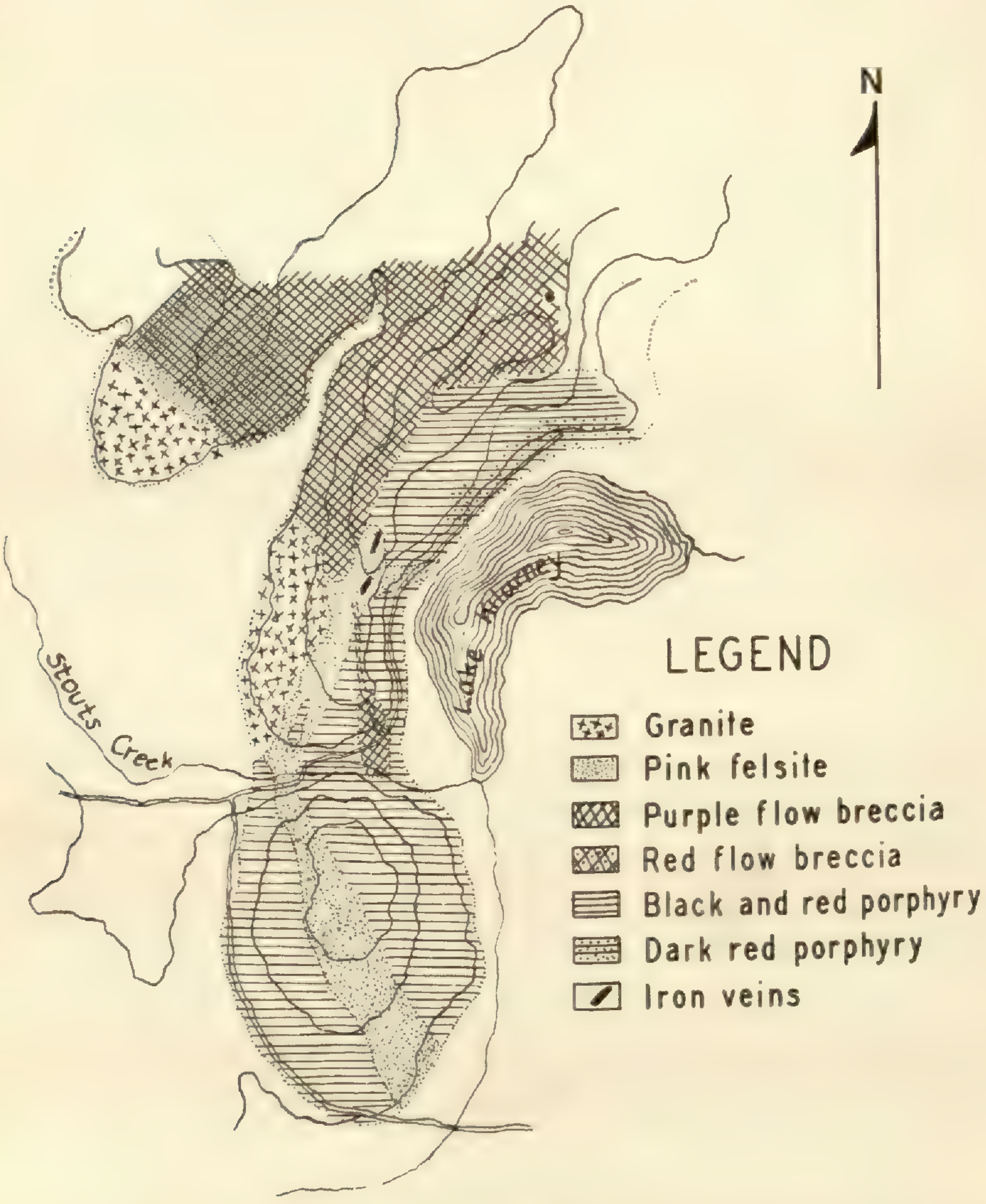


PLATE VI. AREAL GEOLOGY OF STOUTS CREEK SHUT-IN

the black porphyry is an intrusion into the flow breccia, the isolated mass of breccia might be a roof pendant or downstoped block. No contacts between the black and red porphyry and the purple flow breccia were found. On the northwest side of the ridge, fragments of a red porphyry are included in the purple flow breccia. Across the valley to the northwest, the flow breccia is red with purple fragments and, close to the granite, the breccia becomes entirely red.

A pink rhyolite crosses Stouts Creek at the west end of the shut-in, just west of the bridge. This felsite forms a band 350 feet wide which runs the length of the hill to the south of the shut-in. It may be traced up the slope to the north of Highway 70 across the hill and down again to the road. Flow lines are roughly parallel to the borders of the body of rhyolite. The contact between the pink rhyolite and the black and red porphyry is well exposed on the hillside north of the road above the east end of the bridge over Stouts Creek. It is vertical and very sharp, indicating the pink rhyolite was intruded after the black and red porphyry had completely cooled. Quartz phenocrysts are abundant in the pink rhyolite close to the contact, but disappear 15 feet from it.

There are two exposures of a fine-grained, red granite north of the shut-in on the west side of the ridge which are apparently intrusions in the felsite. Although the contact was not seen, typical felsite occurs 20 feet from typical granite indicating that the contact is fairly distinct. Apparently there is gradation between the felsite and the granite because of recrystalization of the felsite by the intrusion of the granite. Tarr (43) cited this locality as an example of the intrusive relationship of the granite to the felsite and stated that the felsite had been recrystalized. The fact that there is more recrystalization at this locality than there is near granite contacts in other localities indicates that the felsite here was still hot when the granite was intruded. The close relation of the two intrusions is shown by the fact that they are similar in composition and both contain abundant masses of specularite.

The relation of this area to the Ironton fault is not clear, but apparently the fault passes to the west of the shut-in. The alignment of the granitic intrusion and the pink rhyolite south of the shut-in suggests intrusion along a fault parallel to the Ironton fault. This fault would have to be of small displacement, however, as the black and red porphyry outcrops on both sides of the rhyolite intrusion. There is a suggestion of structure at right angles to the trend of the Ironton fault in the strike of the contact between the flow breccia and the black and red porphyry and in the northeastward bending of the intrusive rhyolite. Mapping in detail with a more accurate base would give a clearer idea of the relation between the strike of faults, contacts, and flow lines and might indicate whether the dips of the felsite were due to folding before faulting, drag along fault planes, or to intrusion.

Belleview Valley has the appearance of a down-dropped block. Plate II shows this valley, as a square area of Paleozoic rocks surrounded by pre-Cambrian rocks, in the western part of the Iron Mountain quadrangle and the eastern part of the Edgehill quadrangle. It is bounded on the northeast by the Ironton fault with the straight escarpment along Buford Mountain which has already been mentioned. On the northwest, the boundary is marked by the straight side of Logan Mountain and by a small outcrop of granite at the eastern end of the mountain. The southeast side of this block is bounded by the felsite hills along the Black River road and by the course of the headwaters of the East Fork of the Black River. Dake (11) mentioned these three linear topographic features as suggesting pre-Cambrian faulting. The southwest boundary of this block is not marked by any escarpment which suggests that this was a hinge, the greatest movement on the block being on the Buford Mountain edge. However there has been some faulting along the southeast boundary for basic dikes lying along the boundary line show displacement. The eastern corner of the block contains the Graniteville granite mass which has apparently been intruded along the fault planes.

The straightness of the boundaries of the Belleview Valley can only be explained by erosion along nearly vertical faults. The sides of the blocks parallel the two most important sets of joints in the area but erosion along joint planes would produce narrow, parallel valleys rather than such a large and broad depression. Streams do not follow a single set of joints for any great distance, but tend to follow the set of joints best developed at each point along their courses.

Hogan lies at the north corner of another downdropped area similar to the Belleview block. Two granite outcrops southwest of Hogan lie on the northwest edge of the area. The northeast boundary is an extension of the line forming the southwest side of the Belleview block and suggests the continuation of the same fault. This line passes through the two granite areas beyond the boundaries of the main igneous area, suggesting a fault striking northwest through the whole St. Francois Mountains block. The assumed fault along this line may be called the Hogan fault.

The East Fork of the Black River continues on a straight southwest line beyond the Belleview block to the edge of the igneous area. The straight southeast end of Buford Mountain and the northwest side of Iron Mountain also lie along this line. In the northeast corner of the Iron Mountain quadrangle and the southeastern part of the Bonneterre quadrangle, the St. Francois River likewise flows along this alignment. Stream valleys along this alignment are pre-Cambrian as is indicated by the presence of Cambrian sedimentary rocks in the valleys. The granite porphyry of the Edgehill quadrangle lies northwest of the alignment, but its relation to the faulting has not been determined. The fault believed to follow this topographic alignment may be termed the Munger fault.

The iron deposits at Iron Mountain may be due to solutions following along the Munger fault plane from the Ironton fault. The deposits properly owe their location to a minor fault intersecting the Munger fault at Iron Mountain. Faults mapped in the Bonneterre quadrangle(8) as stopping at the southern

boundary of the quadrangle, would if continued pass close to Iron Mountain. The fact that a fault zone passes by Iron Mountain is shown by the displacement of iron veins in the Big Cut. Crane (10) states that the abrupt termination of ore bodies in the underground workings at Iron Mountain suggests the influence of faulting. The presence of a brecciated zone beneath the ore vein on Little Mountain (10) also suggests faulting although this may be a flow breccia or an agglomerate.

The age of the faulting is pre-Cambrian and it is earlier than the iron solutions, for they followed the fault planes. Iron veins are cut by a basic dike at Iron Mountain (10), but it is possible that this dike is younger than most of the dikes of the region and it may be genetically related to the iron veins. Dikes in the Edgehill quadrangle are apparently cut by the faults (11) which may indicate that these dikes are older than the faulting or they may be faulted by a recurrence of movement along fault planes formed earlier. The fact that the major faults of the region trend northwest while the majority of basic dikes strike northeast is evidence that most of the dikes preceded the faulting. The few dikes which strike northwest may belong to a later period of intrusion.

The intrusion of granite along the faults suggests that the faulting is older than some of the granites. The granite intrusions which lie along fault planes do not have the northeast striking basic dikes intruded into them which indicates they belong to the younger granites. At Cornwall and southwest of Coldwater, these younger granites contain basic dikes striking northwest which is further evidence that the intrusion of the dikes followed the faulting.

Major Structural Units

A number of tectonic units involving more than one type of structure and affecting rocks of different ages may be more appropriately discussed as distinct from the structures described on preceding pages. In most cases these units take the form of rectangular blocks of pre-Cambrian rocks which apparently have been pushed up through the later formations.

Ozark Dome

The Ozark Dome is an uplifted area occupying the southern half of Missouri and extending into northern Arkansas and eastern Oklahoma. The two main periods of movement are shown by the major structures which are the Springfield anticline and the northwest trending folds and faults with underlying pre-Cambrian fault blocks. The difference in age between these structures is brought out by the difference in trend of the Ordovician-Mississippian and Mississippian-Pennsylvanian contacts in the southwestern part of the dome. The Springfield anticline is the present axis of uplift. In addition to the folding and faulting there have been repeated uplifts of the dome as a whole, as shown by the numerous unconformities throughout the stratigraphic section.

The boundary of the uplift on the east side is quite sharp. East of the St. Francois Mountains the Paleozoic rocks all dip to the east and faulting which has already been described, occurs there. The boundary is marked by the Ordovician-Mississippian contact through St. Louis and Jefferson counties, by the Mississippi River from Crystal City to a point north of Wittenberg, and by the fault zone from McBride, Missouri, to the edge of the Gulf Embayment in southern Illinois. The boundary as a whole is quite straight and trends N. 50° W., parallel to the strike of pre-Cambrian faults.

The southeastern boundary of the uplift is marked by the border of the Gulf Embayment as far as Batesville, Arkansas. The straightness and southwest trend of the border of the embayment suggest an underlying pre-Cambrian fault. From Batesville, the boundary of the Ozark Dome strikes west into Oklahoma. The southwestern end of the Ozarks, in Oklahoma, is marked by a number of normal faults which are roughly parallel to the Springfield anticline.

The northwest boundary of the Ozark Dome is not as sharp as the boundaries on the other sides. The Pennsylvanian-Mississippian contact trends northeast from the northeast corner of

Oklahoma to the Missouri River east of Marshall, Missouri. The Ordovician-Mississippian contact strikes northeast into Webster County, Missouri, where it turns and trends northwest nearly to the Mississippian-Pennsylvanian contact. The Mississippian rocks outcrop in a narrow band between the Ordovician and Pennsylvanian along the northern boundary of the Ozark Dome, indicating a steeper dip than that of the western side of the dome, a decrease in thickness of beds to the north, or a combination of these two factors.

The rather abrupt boundaries of the uplift on the northeast and southeast suggest that the Ozarks owe their form not only to the intersection of the northwest and northeast structural systems but also to the uplift of the whole region as a block. This uplift is also indicated by minor blocks within the main uplift. The boundary between the Ordovician and Mississippian in Greene County, Missouri, is marked by faults and folds crossing the Springfield anticline. These structures indicate an uplift of the area of exposed Ordovician separately from the Mississippian area. The gentle dips on the southwest border of the dome and the relatively steeper dips on the northwest suggest the action of pressure from the southeast, with the southwest side acting as a hinge. This is the same relationship as exists in the St. Francois Mountains block.

St. Francois Mountains block. From Plate II it may be seen that the igneous rocks of the St. Francois Mountains form a rough square, the sides of which are oriented in northeast—southwest and northwest—southeast directions. The structural nature of this block is not evident from the dip in the surrounding sedimentary rocks inasmuch as initial dips seen throughout the igneous area conceal any due to uplifting of the block. Evidence of the structural nature of the block is seen in the presence of faults parallel to the boundaries of the igneous rocks, in the trend of streams near the boundaries, and in the fact that the strike of the sides corresponds with the major structural trends of the state as a whole.

The northwest side of the block is marked by a straight northwest—southeast trend of the Big River for a distance of over eight miles. The northeast branch of the Palmer fault, called the Big River fault, runs along this side for a distance of three miles near the northern corner of the block. The corner is cut off by the Irondale fault which here trends nearly east—west. Immediately south of this fault there are two small outcrops of granite which are irregular in shape but elongated northeast—southwest.

The northeast side of the St. Francois Mountains block is bounded on the northern end by a continuation of the Irondale fault which here turns southeast. Near Doe Run there is a fault parallel to it just southwest of the pre-Cambrian boundary. A drill-hole near Doe Run passes through a green dike in the Bonneterre (44). There are no known faults between Doe Run and Mine La Motte to the southeast where the Mine La Motte fault runs just ouside the igneous area and parallel to it. At this point the edge of the block projects beyond the general boundary line due to displacement along this fault.

The southeast side of the block has another area projecting beyond the main boundary of the block, and the apparent end of this projection is in line with the Ironton fault. Southwest of Coldwater, there is an area of granite along the boundary line which has already been discussed. A shear zone in the granite strikes north—south and is probably due to faulting. The granite has been mineralized, the solutions apparently following the north—south shear zone. A basic dike, 20 feet in width, strikes N. 45° W. and may follow a fault. Southeast of this granite, there are two other small outcrops west of Bear Creek. A line drawn through these outcrops would pass through the granite near Hogan, thus suggesting that the granite lies on a continuation of the Hogan fault.

The southwest side of the block is parallel to, and southwest of, the Black fault zone. Beyond the fault, the Middle Fork of the Black River continues on the same line for ten miles. In about the middle of this side of the block there is an indented

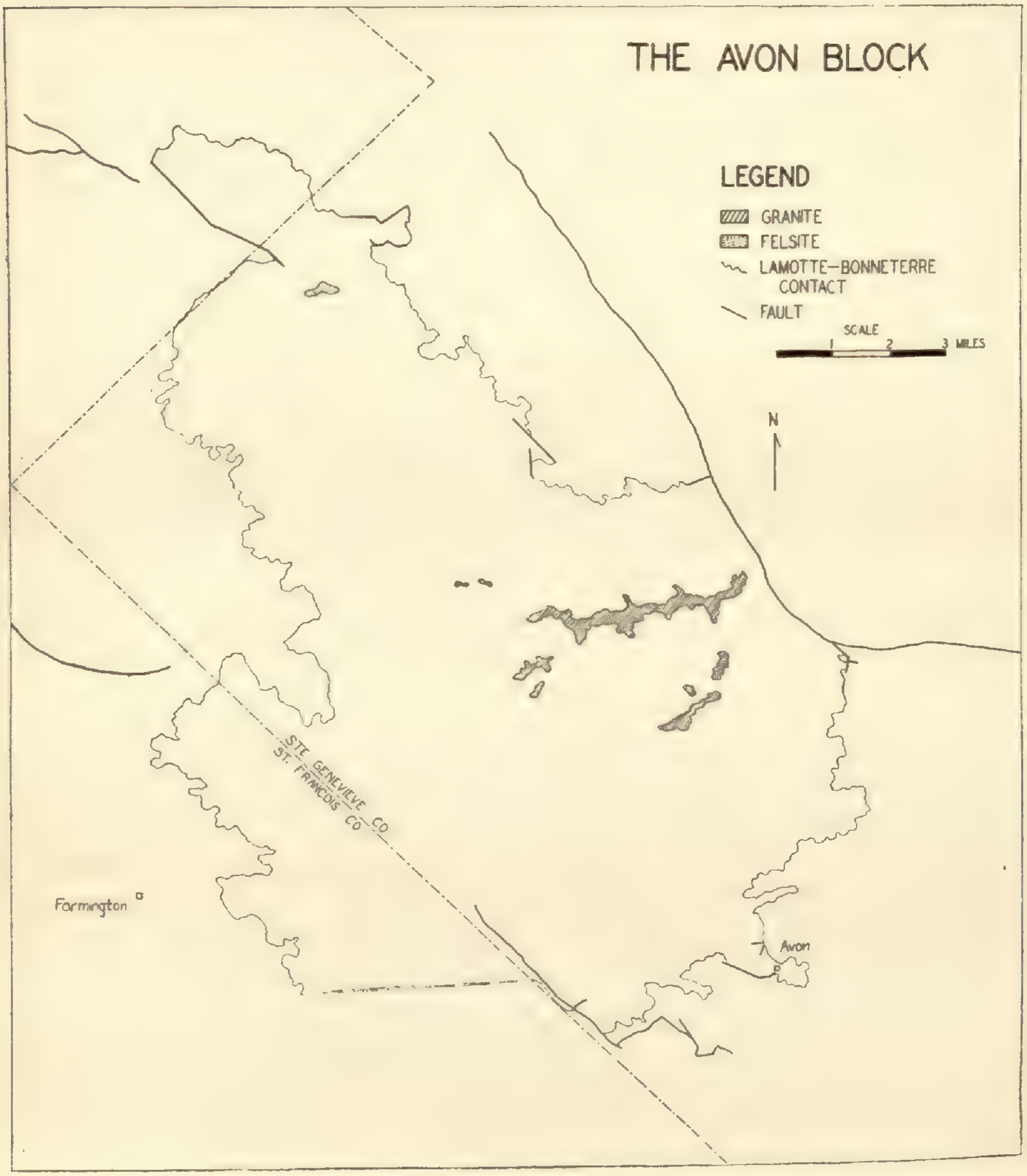


PLATE VII. THE AVON BLOCK

area about seven miles wide by eleven miles long which has already been referred to in connection with the Hogan fault.

From the above description of the St. Francois Mountains block, the characteristics as listed below may be used in recognizing pre-Cambrian blocks in other parts of the state.

1. Presence of pre-Cambrian rocks.
2. Presence of granite intrusions along the supposed boundaries of the blocks.
3. Faults in the Paleozoic rocks along the boundaries.
4. Straight courses of streams for a considerable distance along the boundaries.
5. Presence of pre-Cambrian and post-Cambrian basic dikes along the boundaries.
6. Northeast or northwest trend of structural and physiographic features along the supposed boundaries of the block.
7. Northwest trending faults cutting through the block.
8. Projections and indentations whose sides are parallel to the sides of the block.
9. Mineralization around boundaries of the block.

Avon block. Northeast of Farmington, in Ste. Genevieve County, there is an area of Lamotte sandstone surrounded by the Bonneterre formation. Weller and St. Clair have called this the Farmington anticline (49), but it is here named the Avon block from the town of Avon on the southern extremity of the uplifted area.

The boundaries of the area are shown on Plate VII which was adapted from the geologic map of Ste. Genevieve County. Tarr and Keller (44) describe a basic dike of post-Devonian age which occurs along the southeastern border of the Avon block and mention the occurrence of other similar dikes in that vicinity. Singewald and Milton(40) describe the occurence and discuss the petrology and related mineralization of an alnoite dike intruded into the Bonneterre formation near Avon. More recently Rust (36) has increased the number of known

post-Cambrian igneous occurrences in the southern portion of the Avon block from five to seventy-one and described them as "debris choked explosion tubes (diatremes)". The northwest—southeast and northeast—southwest trends of the Lamotte-Bonneterre contact are quite striking. A number of faults occur along the contact, in some cases bordering projections from the main outline of the block. The part of the contact in St. Francois County lies outside of the area covered by the Ste. Genevieve County map but it is probable that the contact does not go far south of this line for the line is approximately on the northern border of the Mine La Motte quadrangle and the Lamotte formation is not shown extending down into that quadrangle.

The fault indicated east of the county boundary in the southern part of the block is in alignment with the indented area northwest of it. A large number of post-Cambrian igneous occurences appear in groups which show a slight northwest—southeast alignment along a line which passes slightly to the southwest of Avon (as mapped by Rust(36). This alignment may indicate a possible line of pre-Cambrian weakness or faulting. The only lead deposit in Ste. Genevieve County that has been worked to any extent lies on the southern tip of the projection at Avon (49).

Apparently there was little movement of this block as a unit, as is shown by the small displacement along the faults. However this block, with that of the St. Francois Mountains, formed a larger unit with considerable displacement evidenced by movement along the faults on the northwest and northeast sides of the area.

Shannon County block. The Shannon County block is located in southeastern Shannon County and northwestern Carter County. It consists of an area of pre-Cambrian felsites forming a rectangle elongated in a northwest—southeast direction as shown in Plate II. There are no known faults nor igneous intrusions along the boundaries of the block. Bridge (3) points out the block-like nature of the area and suggests the possibility of

pre-Cambrian faulting. He calls attention to the mineralization along the southwestern side as being indicative of buried marginal faults.

A number of large springs in the region are located along the edges of the block. Alley Spring lies to the west of the block and Blue Spring is on the eastern edge of the block. Big Spring is located near Van Buren, west of an outcrop of granite. A line from this locality passing through a projection on the south side of the Shannon County block would pass through Round Spring to the north of the block. This alignment would follow the course of the Current River, along which are a number of large springs, for a distance of 30 miles from Round Spring to Montauk Spring. The alignment of springs suggests a pre-Cambrian fault through the block, along which there has been some Paleozoic movement with too small a displacement to produce recognizable faults.

The Lamotte sandstone is absent in this area, the basal sedimentary rocks ranging from Bonneterre to Gunter in age. This suggests the block was already elevated during Lamotte time. Apparently the St. Francois Mountains were uplifted later, but the Shannon County block did not move with them. Probably nearly all of its elevation is due to pre-Cambrian movement.

Bourbon uplift. The magnetic map of Crawford County (21) shows an area of high vertical anomaly to the east of, and parallel to, the Leasburg fault, which seems to indicate a buried ridge extending from the St. Francois Mountains. The greatest anomaly is immediately west of the town of Bourbon and is higher than at localities where the pre-Cambrian is nearer the surface, suggesting the presence of a buried basic intrusion or a large body of iron ore (21). This anomaly is on a line with the Ironton fault and indicates that the fault continues under the Paleozoic sediments to this point. Further evidence of the existence of the underlying pre-Cambrian block is seen in the outcrops of felsite just west of the northwestern end of the Shirley fault.

The uplifted area is bounded on the northeast by the Shirley and on the southwest by the Leasburg fault, both of which strike northwest—southeast. The Leasburg fault is on the same line as the Hogan fault and also a small fault near Berryman. The Courtois River flows along this alignment from Brazil to the Meramec River. A fault crosses the Gasconade River on a continuation of this same alignment to the northwest. These minor faults indicate an underlying pre-Cambrian fault 115 miles in length.

Decaturville uplift. An outcrop of pegmatite surrounded by steeply dipping Paleozoic rocks southwest of Decaturville, has long been known as the Decaturville Dome. The pegmatite is quite coarse over the small area in which it outcrops. Shephard (37) reported a mass of mica schist and boulders of quartzite over the pegmatite. The Potosi formation outcrops near the igneous rock and it is surrounded by ringlike outcrops of sedimentary rocks ranging from Bonneterre to Jefferson City in age. Rocks close to the pegmatite are nearly vertical but the dip becomes more gentle with distance from the pegmatite. Limestone close to the pegmatite is highly silicified and contains galena and sphalerite.

The age of the pegmatite is still in doubt. Winslow (52) considers it to be intrusive into the sediments and therefore Paleozoic or later. Shephard (39) at first believed it to be pre-Cambrian and describes the Decaturville pegmatite as being "without much doubt a portion of one of the early Archean islands." He also believes that there had been later uplift along the same lines to account for the present disturbed state of the sediments surrounding the pegmatite. In a later paper he expresses the belief that the uplift is due to intrusion of the pegmatite into the sedimentary rocks and points to the presence of quartzite and schist as evidence of metamorphism by intrusion (37).

Drill holes in other localities have entered schists and quartzites of pre-Cambrian age so that the small amount of metamorphic material in the Decaturville Dome does not indicate intrusion into the limestone. Small pegmatitic bodies occur in the

PLATE VIII, THE DECATURVILLE UPLIFT

Graniteville granite and larger ones might well occur in other pre-Cambrian rocks. The Decaturville Dome is part of an uplift too large to be explained by the intrusion of a dike. Dips of the sedimentary rocks around the dome may be explained in part by initial dip and in part by later elevation of the pre-Cambrian surface. That there has been the latter movement is shown by the presence of a fault to the northwest, as shown on Plate VIII. Silicification of the limestone in contact with the pegmatite may be due to groundwater following the contact.

Shephard (39) recognizes the fact that the Decaturville Dome is part of a much larger uplift, and states that the Paleozoic rocks increase in elevation from Greene County towards the dome. This larger uplift is outlined by the contact of the Roubidoux and Jefferson City formations as shown on Plate VIII. While the area is elongated northeast—southwest, it is made up of a series of northwest—southeast trending folds. The main axis is the Proctor anticline which extends from the Benton County line, through Morgan into Camden County. The Osage River follows this alignment for nearly five miles with Linn Creek continuing along this same line for a nearly equal distance south of the river.

Parallel to the Proctor anticline and to the west of it, an anticline extends from Hahatonka across the Osage River. From the Niangua River to Hahatonka there is a fault immediately west of the anticline. South of Hahatonka, Spencer Creek continues on this northwest—southeast structural axis nearly to Decaturville where it turns northeast. The axis of the Decaturville Dome strikes northeast—southwest across the line. South of the dome, the northwest—southeast alignment is continued by Dry Auxglaixe Creek for about seven miles. This trend probably represents a pre-Cambrian fault along which there has been later movement. Displacement along the fault in the Paleozoic rocks has been too small to account for the elevation of the pegmatite at Decaturville. Although the Decaturville Dome appears to be on the downthrown side of the fault plane, it probably represents a projection along the edge of a pre-Cambrian block similar to those seen on the Avon block.

East of the Proctor anticline, there is a broad, anticline extending northwest through the southeastern part of Morgan County (30). East of this area in Miller County, a small anticline crosses the Osage River southwest of Tuscumbia (1). The Osage flows east along the side of this anticline for about four miles. South of Tuscumbia there is a small dome. To the east another anticline crosses the river and on the south side of this anticline there is a small dome. West of St. Elizabeth, the river turns north along the axis of an anticline.

Granite boulders occur along the Osage River on the northeast trending stretch near Tuscumbia and another boulder is located at the bend of the river near Henley (1). These boulders have been thought to be of glacial origin, either directly transported or ice-rafted. They are smooth but show no striæ. The location of these boulders on the crests of anticlines may be in indication that they are derived from the underlying pre-Cambrian rather than being erratics. The Decaturville Dome was located by the presence of igneous boulders before the pegmatite was seen in place. Simliar boulders in northern Moniteau County (48) are probably erratics for here they lie on the Jefferson City formation with no indication of any uplift in the locality.

Pike County uplift. Along the Mississippi River, north of the Missouri River, there is an area of Ordovician rocks elongated in a northwest—southeast direction as shown in Plate I. This area extends from the Cap au Gres fault in Lincoln County northwest through Pike County into Ralls County. The Lincoln fold and Cap au Gres fault strike about N. 70° W., but turn at the west end to strike N. 20° W.(29). The axis of a fold continues the northwest trend throughout the area discussed. The difference in trend of the present structure with the outcrops of Ordovician rocks suggests that the Ordovician rocks owe their elevation to uplift before folding. This may be the result of movement along pre-Cambrian structures in late Ordovician time, followed by post-Pennsylvanian folding. The northwest—southeast struc-

tural axis continues from the Ordovician area, north to the Iowa line, as is evidenced by the trend of the majority of streams.

Origin of Structures

The Strain Ellipsoid

Definition and description(34). The strain ellipsoid represents the form taken by a sphere after yielding to stress, providing there is no dilation. The ellipsoid has three axes mutually perpendicular and of unequal length. The axis of greatest shortening is the axis of greatest stress. The axis of greatest elongation lies in a plane at right angles to the stress and parallel to the direction of easiest relief. The intermediate axis lies perpendicular to the other two and is intermediate in length but is not the arithmetical mean. As ease of relief becomes equal in all directions in the plane normal to the axis of maximum stress, the intermediate and short axes approach each other in length.

When the original sphere is superimposed upon the strain ellipsoid, it intersects the ellipsoid in four places. These intersections line on the planes along which there has been no distortion. These planes represent the only spherical sections through the ellipsoid and are the planes of maximum shear. The shearing planes parallel the axis of intermediate stress. When the intermediate and short axes become the same length, the planes are replaced by cones whose axis is the axis of maximum stress.

When stress is first applied, the shearing planes are at 45° to the stress but this angle increases as the object is deformed. According to Hartman's Law, the angle between the shearing planes is acute toward the direction of compressive stress in the case of plastic material.

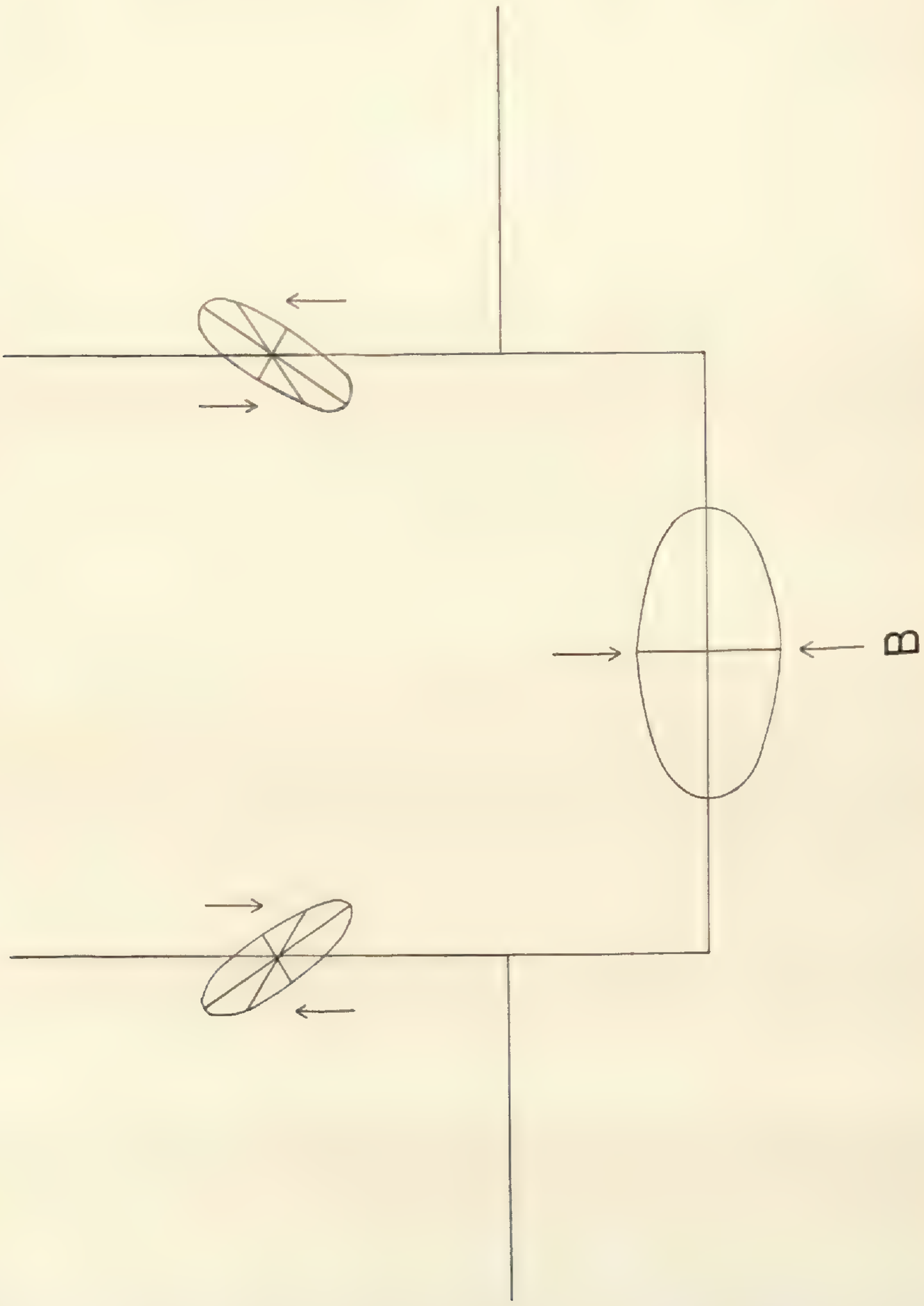
Strain ellipsoid series. The strain ellipsoid is most commonly represented on paper by an ellipse drawn in the plane of axes of maximum and minimum stress. This allows the shearing planes to be shown as they would not appear in sections

parallel to the other two axial planes. Plate IXA shows the series of ellipses produced by decreasing the stress until it has as strong a negative value as it formerly had positive. The same series is obtained by rotating the forces through 180° as is shown by the dotted arrows. This is due to the fact that strain occurs only where stress is resisted so that the only component or each stress that results in deformation is the component directly opposite in direction to the opposing stress. In this series, the forces are considered as acting in couples, each member of which is of equal strength and acting parallel to the other but in the opposite direction. Each force is considered as acting at a single point which is indicated by the heads of the arrows.

The above series shows that the direction of stress does not control the orientation of the strain ellipsoid, but governs the intensity of strain. The orientation of the ellipsoid depends on the location of the stresses relative to the object being deformed.

Application of strain ellipsoid to structure. All tectonic structures are parallel to either the shearing planes or to the axes of the strain ellipsoid. When several structures of the same age are present in a region, it is possible to orient the strain ellipsoid for the forces producing the structures. It is necessary to know that the strucures used in orientation are of the same generation because structures of other periods of deformation may demand different orientations. A later stress may act along pre-existing structures although it is acting from a different direction than the original stress. In the latter case there may be minor structures which indicate that a second stress was active. Major stresses may lead to secondary structures which require a different orientation of the strain ellipsoid than the primary structure.

Folding is caused by compressive stress and the axis of the fold parallels the intermediate stress axis of the strain ellipsoid when the axial plane of the fold is parallel to the intermediate and long axes of the ellipsoid. Cleavage may also lie in this plane or may parallel the shearing planes (14).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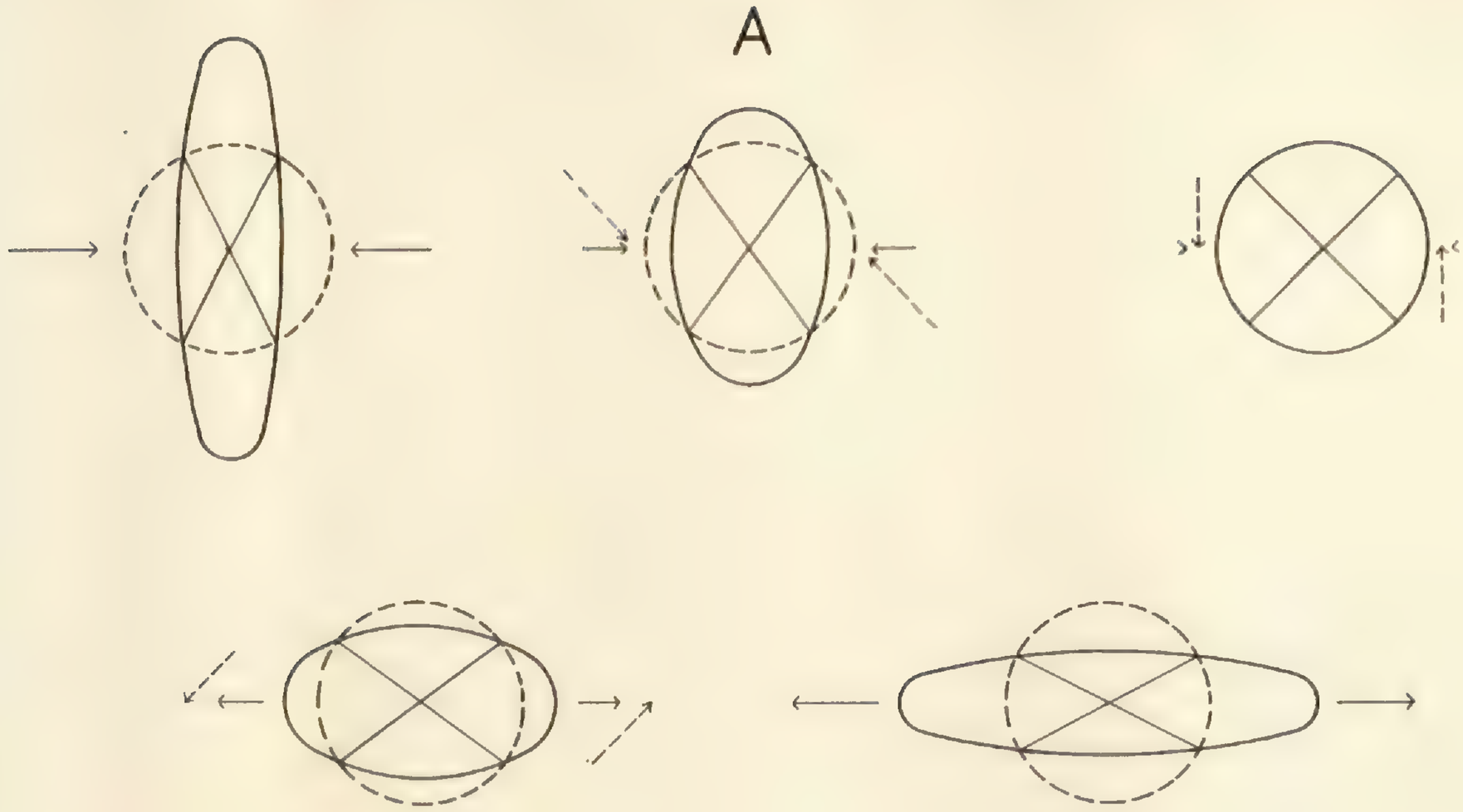

PLATE IX. A. STRAIN ELLIPSE SERIES
B. PRIMARY AND SECONDARY FAULTING

Faulting consists of movements parallel to the walls of a fracture and is therefore due to shearing. Thrust faulting is due to compression and results in crustal shortening while normal faulting is due to tension and results in crustal elongation. Both normal and thrust faults are parallel to the shearing planes of the strain ellipsoid. In many regions of faulting there are vertical faults at right angles to the thrust faults which are parallel to the axes of least and greatest stress as set up for the thrust faults. The vertical faults are the result of horizontal movements and involve neither crustal lengthening or shortening. The term flaw is coming into general use for this type of faulting (35).

An explanation of flaws lies in the production of secondary stresses by the movement due to primary stresses. Differential movement along the zone of thrust faulting caused by varying weakness in the rocks acted upon, will set up horizontal stresses. The vertical faults will form along the shearing planes of strain ellipsoids whose intermediate axes are vertical as the axes of least strain must be horizontal in order to relieve the stress. These relations may be seen in Plate IXB which shows the secondary ellipsoids as smaller than the ellipsoids produced by the major stress.

After the secondary, vertical faults have formed, relief of pressure may allow the formation of normal faults back of the thrust faults, leaving the space between faults as an upthrown block. The formation of upthrown blocks by longitudinal and transverse faulting has been advocated by Stoces and White (41) who believe, however, that the longitudinal faults on both sides of the block are thrust faults. They also state that the transverse faults form only when resistance to folding or thrust faulting becomes too great to allow relief by either of those types of movement.

Joints are fractures along which there has been no movement parallel to the walls. They are formed by tension normal to the joint planes which are oriented parallel to the axes of greatest and intermediate stress of the strain ellipsoid. Two

types of joints are generally recognized although the mechanics of jointing is still not fully understood. The type of joints generally called tension joints differs from other types in the irregularity of the surfaces and in the fact that they are few in number. Joints of this type occur in one set only, normal to the regional tension. The other type consists of joints in two sets which are mutually perpendicular, highly regular, and usually very abundant. They are generally assumed to be shearing plane features (50) but in this case they would be merely thrust faults of very small displacement and so not classified as joints. Nevin (34) recognizes the fact that joints are due to movement perpendicular to the walls of the fractures and that they are mechanically different from faults. He also points out the fact that one set of joints is generally parallel to the dip of the rock and the other set parallel to the strike and that dikes, when present, occur in the dip set only. The division into dip and strike sets of joints has been used in most textbooks of structural geology.

It is possible, in some cases, that joints may occur along shearing planes but, in the majority of cases, a regular joint system has a different origin. In regions where jointing has been carefully studied, it has been found that one set of joints is parallel to the pressure and the other set normal to it. The set parallel to the stress is opened by tension but, unlike true tension joints, the joints in this set are highly regular, due to the fact that the active force is compression rather than tension. This set of joints will be called the dip set for the sake of convenience even in cases where the rocks do not show dip. Fairburn (14) states that the dip joints are usually the master joints of a region but, although they are the most abundant, they are often the least prominent and are therefore overlooked. The strike set of joints which is normal to compressive stress, is more difficult to explain. An open fracture would not be produced by compression. If the joints were merely faults of very small displacement, they would dip parallel to the faults of the region rather than being vertical. A possible explanation is that incipient fractures were formed by compression and were later opened up by relief of pressure. This would

mean that the strike set was younger than the dip set. That the two sets of joints have different origins is indicated in a number of localities by the presence of dikes in one set and not in the other. In most cases the dikes are in the set parallel to the direction of compressive stress.

While the strain ellipsoid may be oriented from the position of the structures present, it may be impossible to determine the direction in which the forces acted. The same strain ellipsoid may be produced by forces acting in a number of directions but the types of structures present may give some idea of the nature of the stresses. The structures formed will be those that will best relieve the stress.

Application to Missouri structures. The most important structural system in Missouri is represented by the N. 40° E. and N. 50° W. joints. Many of the dikes in the pre-Cambrian rocks follow the northeast set of joints indicating that northeast was the direction normal to tensional stress during the pre-Cambrian. This set may therefore be called the dip set and the northwest set the strike set. Faults strike N. 50° W. in both the pre-Cambrian and the Paleozoic rocks, indicating that this direction is parallel to the intermediate axis of the strain ellipsoid and that compressive stress acted in a northeast—southwest direction. That the stress was caused by compression from the southwest, rather than the northeast, is indicated by the fact that fault planes in many cases dip to the southwest.

The presence of dikes in the northeast set of joints may be evidence that this set was formed first and the dikes intruded before the second set was formed. It may, however, merely indicate that this was the direction normal to tensional stress which favored the intrusion of the dikes. The theory advanced for this type of jointing would require the northeast set of joints to be formed first. The presence of later dikes in the northwest set in a few localities may show that this set was formed later, although these dikes may be in fault planes rather than dikes. Faults trending northwest through the St. Francois Mountains are normal faults due to relief of pressure

which elevated the block. This faulting was later than intrusion of the basic dikes and probably of the same age as the northwest set of joints. These relations conform to the theory advanced for the origin of joints.

The block structure of the St. Francois Mountains and Shannon County areas can be explained similarly to the jointing. Thrust faults were formed by pressure from the southwest and were accompanied by vertical, transverse flaws which probably followed previously formed joint planes. Upon relief of the pressure, normal faults were formed parallel to, and southwest of, the thrust faults. This left the blocks outlined on all four sides. During the later periods there was compression alternately from the southwest and southeast which accentuated the block structure.

There is little distinction between the N. 70° W. and N. 20° E. sets of joints, but the former set is much more abundant and there are dikes parallel to it, thus suggesting that it is the dip set. It seems more probable, however, that the stress acted from the southwest, parallel to the N. 20° E. set. The same sets occur in the Wichita Mountains where structures are due to pressure from the southwest. Buckley and Buehler (9) report a southwest dip for a number of the N. 70° W. joints which is further indication that the stress acted from the southwest.

The N.—S. set of joints is more important than the E.—W. and there are dikes in the N.—S. set in the pre-Cambrian rocks. The Palmer fault in Washington and Crawford counties and the Devonian fault in Ste. Genevieve County strike west through part of their length and may both lie above a pre-Cambrian fault.

The N. 70° E. and N. 20° W. system is the least well defined. The N. 60-70° E. joints at Graniteville may belong to this system or may be of local origin. Joints occurring N. 50-60° E. may be either of local origin or belong to this system or

to the N. 40° E. set. Joints striking N. 80° E. may belong to the N. 70° E. set or to the E.—W. set. The Springfield anticline strikes about N. 70° E. and it is possible that the joints originated with the anticline during the Tertiary, as there is no definite proof they are pre-Cambrian.

Source of Stress

The possible sources of the stress forming the joints and faults in the pre-Cambrian rocks include igneous intrusion, vertical uplift, and horizontal compression. While the minor sets of joints may be the result of intrusion, the major structural systems are too widespread to have been formed by anything but major crustal movements. Vertical uplift would produce structures that were unoriented or were radial or tangential to the uplift but structures throughout the state have the same trends indicating horizontal compression over a wide area.

During pre-Cambrian time there were two structural systems developed which were of regional origin. The N. 50° W. and the N. 40° E. system is dominant in Missouri and important in the Llano region of Texas. The N. 70° W. and N. 20° E. system is dominant in the pre-Cambrian of the Wichita Mountains of Oklahoma, and is of secondary importance in Missouri. These systems were developed as a result of compression from the southwest from two somewhat different directions at different times during the pre-Cambrian. The stress must have originated at a considerable distance southwest of any of the pre-Cambrian localities and probably came from the Pacific Ocean basin.

Joints not belonging to either of the above systems may be of local origin or in the case of the N.—S. and E.—W. sets may be due to a minor, but regional, movement. Many of the joints in the pre-Cambrian rocks may be due to movement at a later time but it seems more probable to consider them all of pre-Cambrian age. Until the age relations of the various pre-Cambrian rocks have been definitely worked out, it is impossible to determine the relative ages of the different sets of joints.

Summary and Conclusions

The dominant structural trend in the pre-Cambrian rocks of Missouri is N. 50° W. Pre-Cambrian faults and joints strike in this direction, as do bedding planes in the pyroclastics and flow lines in the felsites. Second in importance are the N. 40° E. structures which include flaws and joints, and the majority of basic dikes also strike in this direction. Minor joint systems in the order of their importance are: N. 70° W. and N. 20° E., N.—S. and E.—W., and N. 70° E. and N. 20° W. It is believed that the pre-Cambrian structures were formed by compression from the southwest and the source of the stress must have been located in northern Mexico or the Pacific Ocean basin as structures in Oklahoma and Texas were apparently formed from the same stress.

The first recorded event in the structural history of Missouri is the extrusion of felsite which was followed by the intrusion of the oldest granite. After the intrusion of the granite, joints striking northeast were formed in both the granite and felsite. Following the intrusion of basic dikes in the northeast joints, faulting occurred and was followed by the intrusion of granite and felsite and the formation of iron deposits. The final events recorded in the pre-Cambrian include the intrusion of the youngest granite, of basic dikes striking northwest, and finally, mineralization.

Structures in the Paleozoic rocks have the same trends as those in the pre-Cambrian. The northwest and northeast-trending structures are due to movements along pre-Cambrian fault planes.

□

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VOLUME XXIX, No. 6

Some Problems of the Middle Mississippi River Region During Pleistocene Time

PERCIVAL ROBERTSON

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PERCIVAL ROBERTSON

A condensation of a dissertation presented to the Board of Graduate Studies of Washington University in partial fulfillment of the requirements for the Degree of Doctor of philosophy, 1936.

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Some Problems of the Middle Mississippi River Region During Pleistocene Time

PERCIVAL ROBERTSON

INTRODUCTION

The area comprised in this study lies along the Mississippi River and its tributaries in parts of the states of Missouri and Illinois. It includes a distance of approximately a hundred miles down stream from St. Louis to the vicinity of Cape Girardeau, Missouri, and a somewhat shorter distance up the Mississippi, Missouri, and Illinois rivers. This area has been called for the purpose of this report the Middle Mississppi River Region. Figure 1 shows the principal streams in this area.

The Pleistocene deposits in this region include drift, its associated outwash and valley train material, lake deposits, and loess. This particular report is concerned principally with the drift, the outwash from it, and the lake deposits whose remnants are seen as terraces along the main streams and more particularly in their tributaries. An abstract of the work done on the loess has been published elsewhere [1]

The author is indebted to a host of individuals who have studied this region previously. A list of all those to whom

Figure 1.

THE MIDDLE MISSISSIPPI RIVER REGION

SCALE OF MILES

0 5 10 20 30

he is indebted would far exceed the space which should be allotted for acknowledgements. Individual citations of the work of some of the more important investigations are made at appropriate places. Special thanks are due Dr. Lewis F. Thomas who suggested a study of the terraces and gave much help.

TERRACES

General Statement

The correlation of the remnants of the terraces along the Middle Mississippi River reveals the existence at earlier times of three distinct and extensive alluvial deposits or terraces in addition to several less important ones. The three larger terraces are not coextensive, and the evidence indicates that they were not formed contemporaneously. By the judicious coordination of the evidence of the terraces with that of the drift it has been possible to reconstruct some of the salient events which occurred in the Middle Mississippi River Region during the Pleistocene.

One of these terraces has a surface slope essentially parallel to the gradient of the Mississippi. This is the most extensive of the three terraces and has the lowest elevation, at least in this region. It is named in this report the Festus Terrace.

Another of these terraces has a surface that is essentially horizontal. This terrace has a very broad extent, north, but not south, of St. Louis. It is always higher than the Festus Terrace within the limits of the region studied. It is called the Cuivre Terrace.

The third of the extensive terraces has been greatly eroded, but the evidence points to the conclusion that its initial surface was essentially horizontal. This terrace is found only along the Missouri River, where it is always higher than the Cuivre Terrace. It is named the Boeuf Terrace.

In addition to these three extensive terraces which may be found in numerous tributaries to the master streams, there are a few terraces found in some of the streams in Illinois south of St. Louis which appear to be independent of one another and of the larger terraces. These are called in this report terraces of the Kaskasia River Type.

THEORETICAL CONSIDERATIONS

In attempting to reconstruct the original surfaces of deposits laid down in a great river system, a few simple facts should be borne in mind. If the deposit were formed by an unobstructed stream in its flood plain, the initial surface of the deposits would have a longitudinal slope equal to the gradient of the stream at the time it was depositing the sediment. If, on the contrary, the deposit were made in a portion of the stream that was temporarily dammed, thereby forming a lake, then the initial surface of the deposit would be essentially horizontal. If a delta were deposited in such a lake, the topset beds would have been horizontal, but the foreset beds would have had a very gradual slope away from the source of the sediment.

In attempting to reconstruct the initial surface of a terrace, care must be taken to eliminate all flat surfaces produced subsequently to the formation of the initial surface, whether by erosion, by rain wash, or by eolian deposition. By properly plotting the terrace fragments on the longitudinal profile of a river, the nature of the original deposit may be ascertained. This is brought out in Figure 2.

METHODS OF STUDY

In the specific region under investigation the structure of the terraces was observed in recent road cuts and in places where streams have undercut their banks, thereby exposing clear sections. Occasionally a soil auger was used. The elevation of the tops of the terraces was recorded, using a Paulin System altimeter, checked as frequently as possible against established bench marks. In some instances where elevations determined

TABLE I. TERRACE DATA.

Localities exhibiting terraces along Mississippi River, with distances from Jefferson Barracks (at south edge of the St. Louis, Missouri-Illinois quadrangle).

SOUTHWARD

Loality on west bank / Locality on east bank	Miles †A	Feet above sea level B	C	D	E
Meramec R.	9	444	———	———	———
Rock Cr.	11	439	———	———	———
Glaize Cr.	13	445	———	———	———
Dennis Hollow	16	470	———	———	———
Riverside	16	470	———	———	———
Joachim Cr.	18	445	———	———	———
Plattin Cr.	20	450	———	———	———
Establishment Cr.	34	430	———	———	———
Prarie du Roche Cr.	36	———	*	———	———
Gabouri Cr.	44	430	———	———	———
Kaskaskia R.	45	430	490	———	———
River aux Vases	48	435	———	———	———
Saline Cr.	50	430	———	———	———
Blue Spring Branch	56	410	———	———	———
Marys R.	59	430	———	———	———
Degonia R.	66	410	———	———	———
Big Muddy R.	80	370	390	———	———
Cedar Cr.	83	370	390	———	———
Brazeau Cr.	84	420	———	———	———
Fountain Bluff	84	430	———	———	———
Apple Cr.	90	390	———	———	———
Clear Cr.	98	370	430	———	———
Dutch Cr.	100	390	*	———	———
Flora Cr.	106	390	———	———	———
Judeau Cr.	109	390	———	———	———
Sexton Cr.	111	370	———	———	———
Cape le Croix Cr.	115	390	———	———	———
Miller Cr.	117	370	———	———	———
Dorrity Cr.	118	370	———	———	———
Hubbel Cr.	120	390	———	———	———

TABLE I Continued

NORTHWARD

Locality on west bank / Locality on east bank	Miles	Feet above sea level			
	A	B	C	D	E
River des Peres	2	450	———	———	———
Prairie du Paul Cr.	6	———	470?	———	———
Maline Cr.	19	440	———	———	———
Watkins Cr.	20	440	———	———	———
Cahokia Cr.	23	———	———	480	———
Indian Cr.	24	———	———	480	———
Wood R.	26	440	———	480	———
Coldwater Cr.	29	445	———	———	———
Nameless Cr.	35	445	———	500	———
Piasa Cr.	35	450	———	490	———
Elsah Cr.	40	———	———	490	———
Bonfils	49	465	———	505	———
Caulks Cr.	57	470	———	508	———
Wildhorse Cr.	66	———	———	510	———
Femme Osage Cr.	67	———	———	508	560
Big Tavern Cr.	70	———	———	510	———
Little Tavern Cr.	71	500	———	520	———
Oetters	74	500	———	———	570
Labadie Cr.	75	———	———	520?	560?
Dubois Cr.	81	———	———	530	570
St. Johns R.	84	500	———	———	545
Little Boeuf Cr.	90	520	———	533	———
Boeuf Cr.	91	———	———	515	———
Big Berger Cr.	100	———	———	530	565
Little Berger Cr.	105	———	———	530	570
Masses Cr.	107	———	———	550?	580
Frene Cr.	110	———	———	530	570

Tributaries on the east bank of stream are indicated by being indented in column below.

†Column A Distance from Jefferson Barracks.

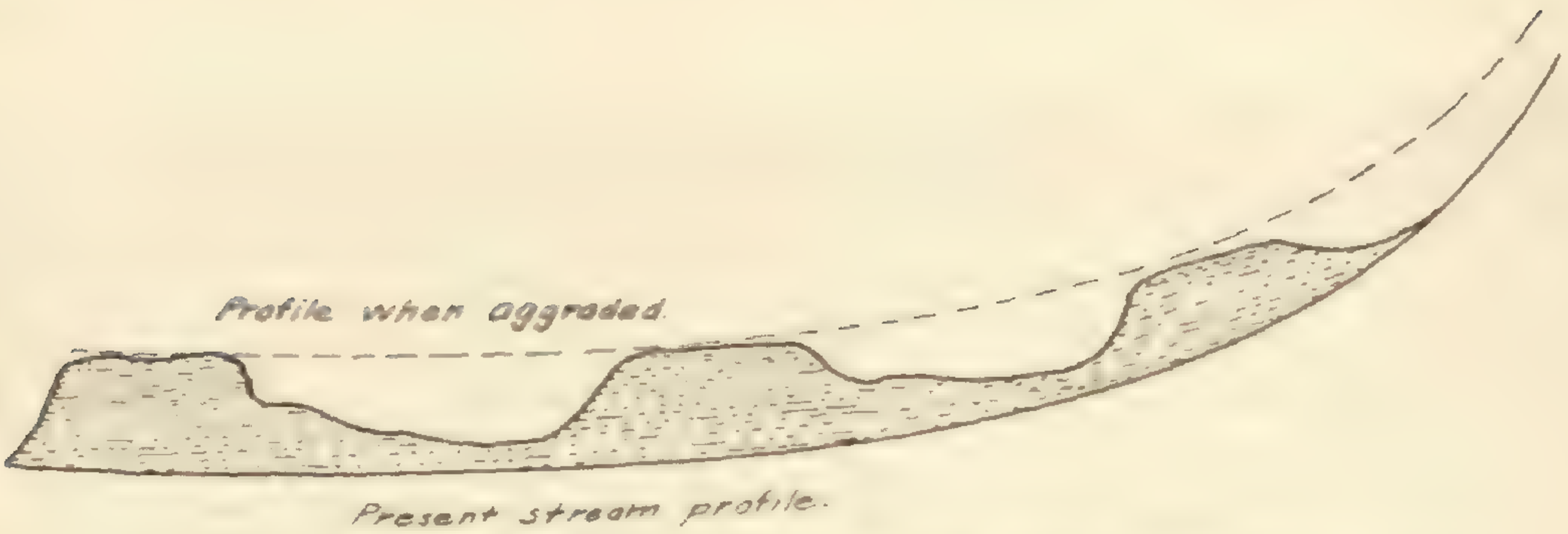
Column B Elevation of Festus Terrace.

Column C Elevation of Kaskaskia River type of terrace.

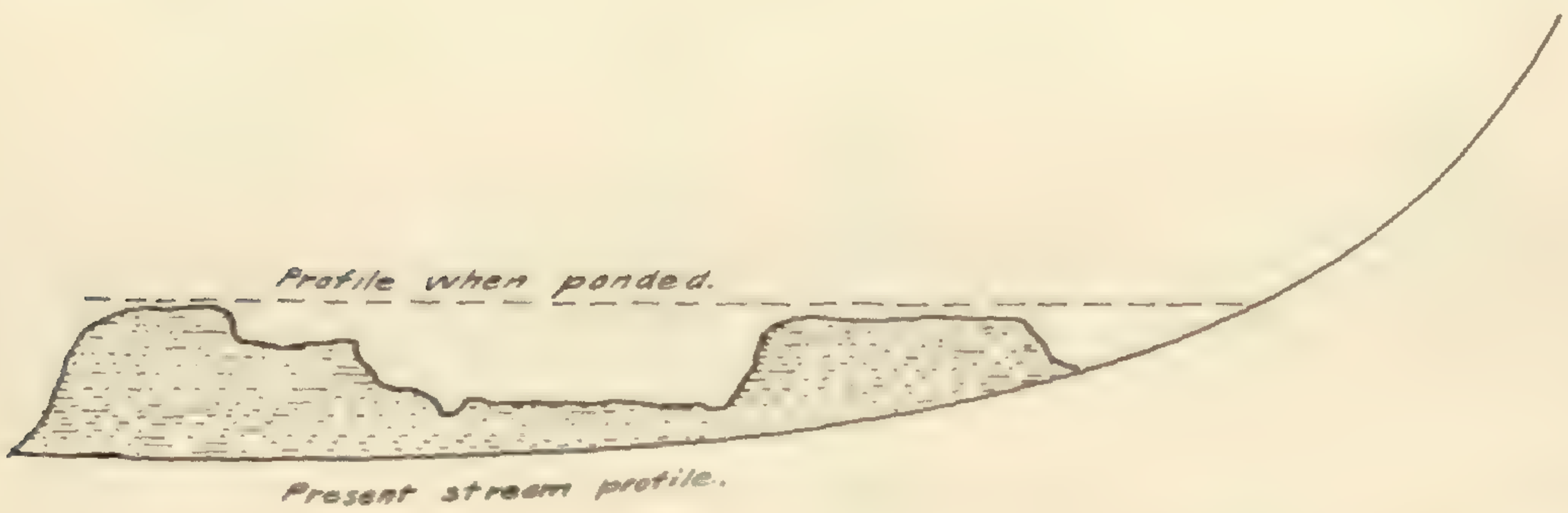
Column D Elevation of Cuivre Terrace.

Column E Elevation of Boeuf Terrace.

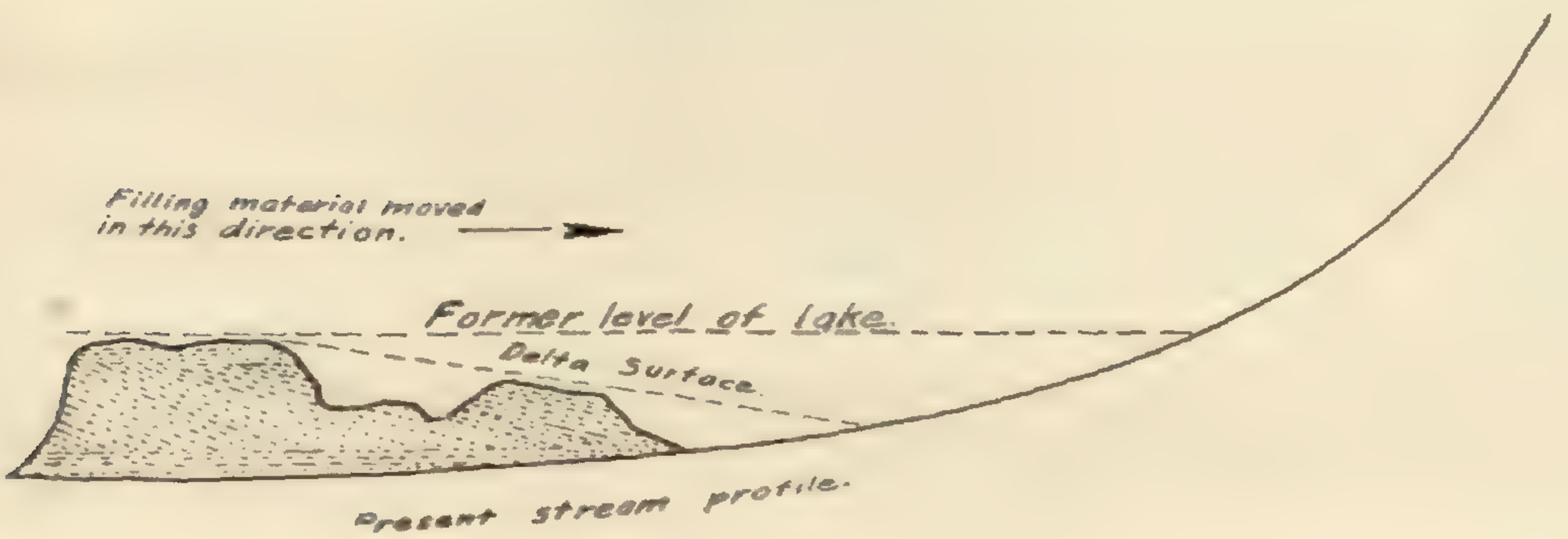
*Terrace present, elevation undetermined.



A. Terrace produced by aggrading and subsequent incomplete removal in an unobstructed stream.



B. Fragments of a terrace produced by deposition in a ponded stream followed by incomplete erosion of the deposit.



C. Delta-like deposit formed in a tributary to a master stream when the master stream was over loaded, followed by subsequent partial erosion of the delta-like deposit. Notice that the slope of the terrace top is contrary to the stream profile.

Figure 2. Types of terraces found in the Middle Mississippi River Region.

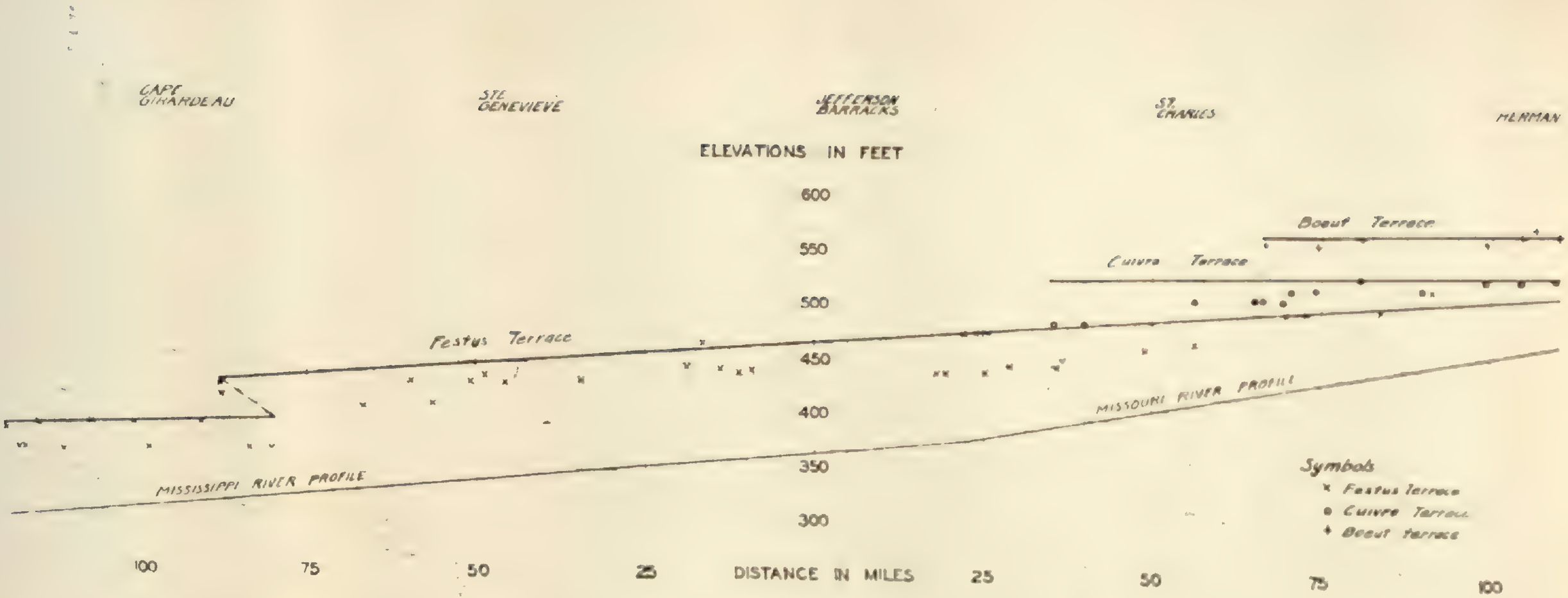


Figure 3. Profile showing the various terraces in the Middle Mississippi River Region.

by the barometer were unsatisfactory or were lacking, elevations were estimated as accurately as possible from topographic maps. Intermediate flat surfaces caused by the erosion of an alluvial terrace and which represent only a very temporary stage in the evolution of the valley were excluded in all cases where they could be recognized. Every effort was made to eliminate surfaces which had been built up by eolian deposition subsequent to the aqueous deposit.

The study reveals that alluvial terraces are far more common than rock terraces, although the latter are not entirely lacking. Where the rock terraces were found, they were regularly covered with a thin veneer of soil of an alluvial rather than a residual nature.

In the case of several tributaries, the terraces were studied for a number of miles along the tributary to determine whether or not the terrace had a slope parallel to the profile of the stream. Some stream terraces have slopes essentially parallel to the profile of the stream. In other cases, the top of the terrace appears to be essentially horizontal; while, in still other cases, the slope of the terrace is actually contrary to the gradient of the stream. A map showing the locations of streams in the Middle Mississippi River Region which have been studied is shown in Figure 1. This map includes other geographic localities referred to in this report.

A correlation of the terraces from stream to stream has also been made. For this purpose, the elevations of the terraces near the mouth of each tributary, together with the elevation of such terraces as may be found in the trough of the master stream, have been tabulated. This data is shown in Table 1. The data have been plotted, together with the longitudinal profile of the mean datum surface of the master streams. To determine distances along the master stream a broken line was drawn essentially along the axis of the trough and the distances were taken as offsets from this line (Fig. 3). Distances are, therefore, slightly shorter than they would be if measured on the axis of the river itself; but since the river channel changes from time

to time, it was felt that this was a more desirable method. The center of the trough of the Mississippi at the southern edge of the St. Louis, Missouri-Illinois quadrangle, about opposite Jefferson Barracks, was used as the point of reference, all distances being computed from this point.

THE FESTUS TERRACE

Near the mouth of Plattin Creek, and for several miles up this creek, fragments of a terrace may be observed. Large areas of the flat top of the terrace may be seen in the vicinity of Festus and Crystal City, Missouri. The elevation of the flat top of the terrace is 445 feet near the mouth of the creek, but this decreases with increasing distance from the Mississippi River. The terrace has completely disappeared upstream before the place where the 440-foot contour crosses the creek. Apparently the upper surface of the terrace displayed in this creek is not parallel to the gradient of the stream, nor is it horizontal; but it has a very slight slope contrary to the direction of the stream. The greatest elevation of the flood plain of the Mississippi is not quite 400 feet in this vicinity. The mean datum plane of the Mississippi is 375 feet opposite the mouth of Plattin Creek. The top of the terrace is, therefore, about 50 feet above the flood plain and 70 feet above the mean datum plane of the river.

A cut immediately west of the First Baptist Church in Festus shows the stratified nature of the terrace (Fig. 4). The terrace consists of alternating layers of silt and fine sand with a few thin beds of fine gravel. None of the layers exceeds a foot in thickness and they are usually thinner. The absence of coarse sand in the terrace at this locality is significant, since the coarse-grained St. Peter sandstone forms conspicious and numerous outcrops nearby. It would appear that this nearby sandstone did not furnish much of the substance of the terrace.

Terraces similar to the one on Plattin Creek can be found in every stream of considerable size between St. Louis and

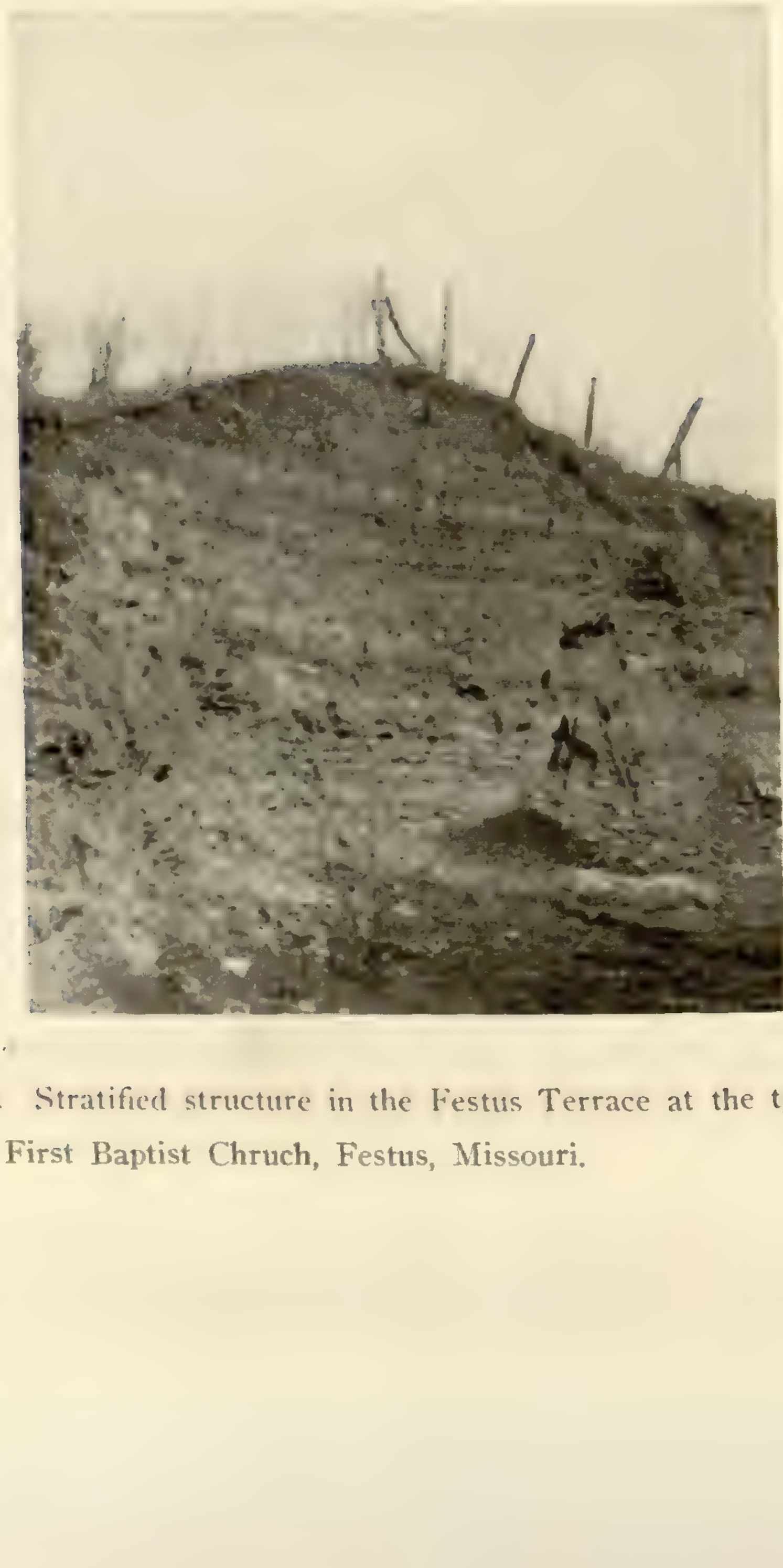


FIGURE 4. Stratified structure in the Festus Terrace at the type locality, near the First Baptist Chruch, Festus, Missouri.

Wittenberg in Perry County, Missouri, on the Missouri side of the river, and in most of the streams on the Illinois side in the same latitude (Fig. 5). The terraces are regularly about 50 feet above the highest portion of the flood plain of the Mississippi. Wherever sections of these terraces can be studied, they are clearly stratified and are composed chiefly of a loess-like silt, to a less extent of fine sand and, rarely, of fine gravel.

The nearly constant difference between the elevation of the top of the terraces and the highest portion of the flood plain of the Mississippi strongly suggests that the terraces are fragments of a deposit made by the Mississippi when it was at a stage at least 70 feet higher than the present mean datum plane. The composition of the terrace supports the idea that the sediment came principally from the Mississippi, and not from the tributaries. The gradual slope of the tops of the terraces in the side valleys away from the master stream supports this idea. This gradual slope away from the master stream has been observed on several tributaries, and it is apparently a usual feature. Further evidence to be presented points to the same conclusion; namely, that the sediment is derived principally from the master stream.

It is, therefore, believed that fragments of terraces, about 70 feet above the mean datum plane of the Mississippi, or 50 feet above the highest portion of the adjacent flood plain of the master stream, found in practically every tributary of the Middle Mississippi River as far south as Wittenberg, Missouri, are fragments of a single deposit formed when the river was at a stage at least 70 feet higher than the present. Detailed work on these terraces shows that the gradient of the Mississippi at that time must have been about four inches per mile. The name Festus Terrace is proposed for the original fluvial plain, remnants of which may be found particularly well exposed near Festus, Missouri.

A study of three tributaries of the Mississippi in Jefferson County, Missouri, and shown on the Kimmswick, Missouri-

FIGURE 5. Level surface of the Festus Terrace at Barnhart, Missouri.

Illinois quadrangle, further emphasizes the fact that the terrace fragments found in the tributaries of the Mississippi are deposits derived from the master stream rather than from the tributary (Fig. 6). Both Rock Creek and Glaize Creek have rather straight courses with terrace fragments along them with elevations which correlate with the Festus Terrace. The next creek south, of approximately the same size, is Sandy Creek. Its trough has a straight course parallel to those of Rock and Glaize creeks, with the mouth of the valley at Riverside. Examination will show that in the lower mile of the valley there is no permanent stream, because at Jerseydale, nearly three miles west of the natural mouth of the valley at Riverside, Sandy Creek passes through a water-gap and escapes southward into the valley of Joachim Creek. The reason is not difficult to find. The terrace at Riverside is unusually broad and high. It completely blocked the course of Sandy Creek, causing it to turn aside through its present water-gap. Such a terrace could hardly have been constructed by Sandy Creek; it must have been made by the Mississippi. The reversal of Sandy Creek by the damming of its mouth can be seen on a map or in the field in the course of an unnamed tributary to Sandy Creek, which flows west from Pevely to Jerseydale along the same course that Sandy Creek previously used in flowing eastward. But a somewhat similar deflection of a stream-course, due to damming of the mouth of the stream by deposits from the Mississippi, can be seen on Hubbel Creek. Before discussing this instance, however, mention must be made of the condition of the terraces south of Wittenberg.

Between Wittenberg and Hubbel Creek, ten miles southwest of Cape Girardeau, a set of terraces similar in all respects, except elevation and slope, to the Festus Terrace may be traced on both sides of the Mississippi. The tops of these terraces have a lower elevation than the Festus Terrace would be expected to have and their slope is also less. But otherwise they resemble the Festus Terrace closely, so closely that it does not seem proper to separate them from the Festus Terrace. It would seem more probable that the terraces above and below Wittenberg were syn-

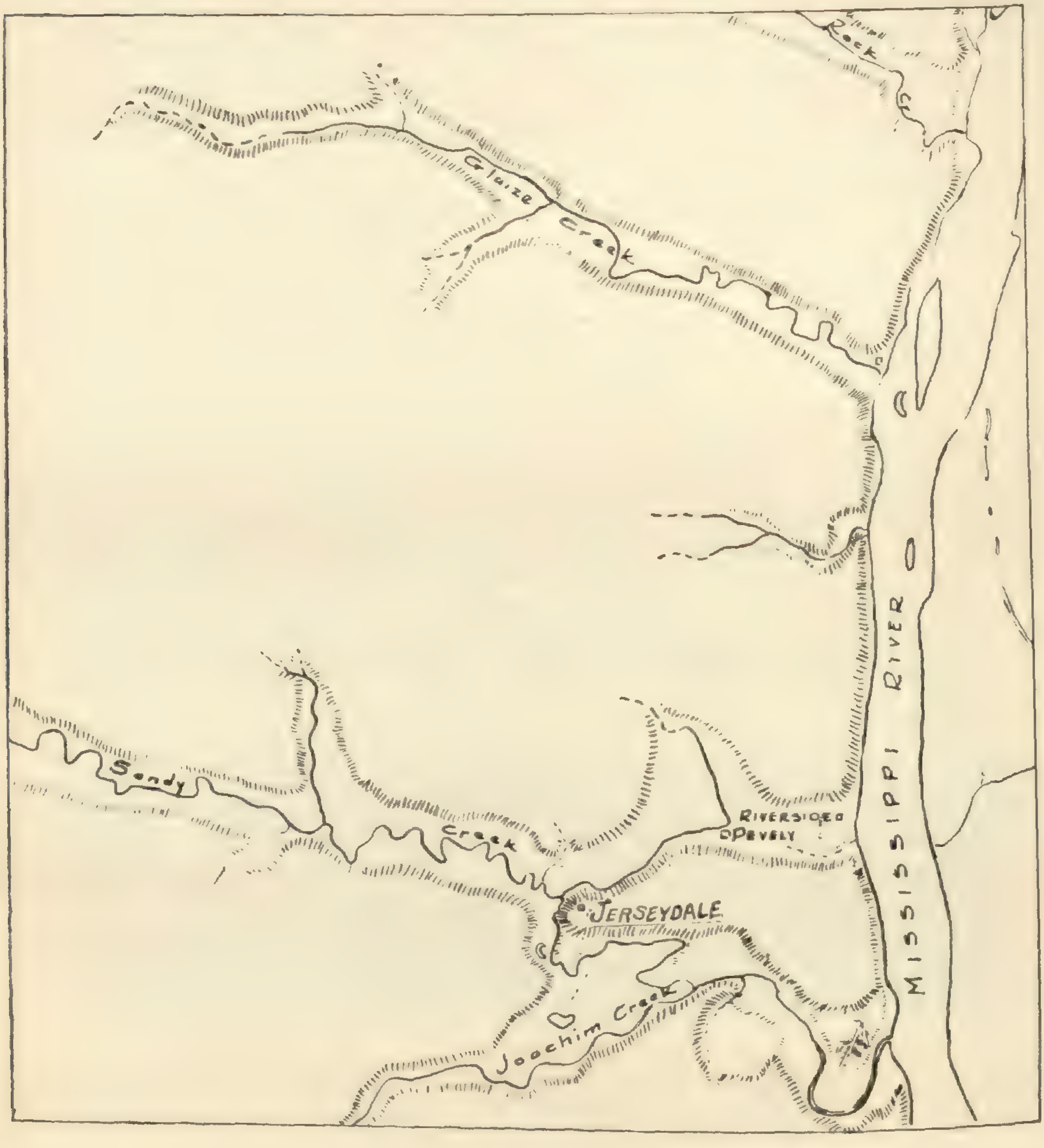


Figure 6. Piracy of Sandy Creek by Joachim Creek, Jefferson County, Missouri.

chronous and that some subsequent event has produced the apparent discrepancy in altitude. It may be significant that the thrust fault described by Flint[2] between Red Rock, Missouri, and Grand Tower, Illinois, practically separates the higher from the lower set of terraces. The number of observations on the lower set of terraces is too few and the total horizontal distance involved is too short (only 36 miles) to give a definite answer as to the cause of the discrepancy. Further study down stream should clear up the matter. Until it is proved otherwise, the terraces between Wittenberg and Hubbel Creek will be considered to be a part of the Festus Terrace.

Hubbel Creek flows in a mature valley for a distance of more than 12 miles. The lower portion of the valley is bordered by terraces composed of sand and silt. Then, just before it reaches the flood plain of the Mississippi, it enters a narrow, steep-walled rock gorge, totally out of harmony with the character of its valley farther upstream. This rock gorge is scarcely a quarter of a mile long and is incised in the St. Peter sandstone. Study of the region shows that there is a broad silt-filled opening in sandstone cliffs a short distance to the east of the present mouth of Hubbel Creek. This helps explain the anomaly. Hubbel Creek was a mature stream flowing in a mature valley. The Mississippi then became an aggrading stream. It filled its own channel to a height of approximately 50 feet above the present channel. The old course of Hubbel Creek also became filled with sand and silt. On this new and flatter surface Hubbel Creek flowed and, as is common in the case of tributary streams, its mouth was deflected a short distance down the course of the master stream. When the Mississippi later became an eroding stream, it cleared the sediment in its own trough. As this occurred, Hubbel Creek became incised in the flat plain. Its upper course was essentially in the same place it had been before deposition occurred and the rejuvenated stream found no difficulty in reexcavating its valley in the alluvium. But the lower portion of Hubbel Creek, which had been deflected, was now flowing over the sandstone belt which formed the rim of the Mississippi River trough. The sandstone being much more re-

sistant to erosion than the alluvium, Hubbel Creek has been unable to widen its trough near its mouth.

Fragments of the Festus Terrace may be traced northward from St. Louis several miles. They are visible in the entire Middle Mississippi River section. As previously pointed out, the gradient of the Festus Terrace is about four inches per mile, while that of the Mississippi and Illinois rivers in this general vicinity is between six and seven inches per mile, and the gradient of the Missouri River is nearer twelve inches per mile. It will then be seen that the Festus Terrace approches the level of the flood plain of the Mississippi upstream, and unless there were some change in the slope of the terrace or the gradients of the rivers, it would be expected that the Festus Terrace would eventually merge upstream with the recent alluvium in the flood plain. This is precisely what happens up the Missouri River. This study did not carry the work up the Mississippi or Illinois rivers far enough to determine whether or not such a merging takes place. Rubey[3] has recently traced a terrace along the Illinois River in Calhoun County, which may be correlated with the Festus Terrace. He called it the Deer Plain Terrace.

THE CUIVRE TERRACE

Between Winfield, Lincoln County, Missouri, and Grafton, Jersey County, Illinois, the Mississippi River flows in a great, semi-circular arc, first south, then east, and then north. This arc is bordered on the west, south, and to a somewhat less extent on the southeast, by two very extensive, flat surfaces. Both can be seen at St. Peters, St. Charles County, Missouri (Fig. 7). The lower one has an elevation of 450 feet. It is a part of the Festus Terrace. The upper terrace has an elevation of about 510 feet. It is to this upper surface that attention is now directed. The surface is somewhat dissected by youthful streams; but the view from the top of the terrace shows the broad expanse of flat surface, which is also shown on the topographic map. The terrace in this vicinity extends along the Mississippi River in a

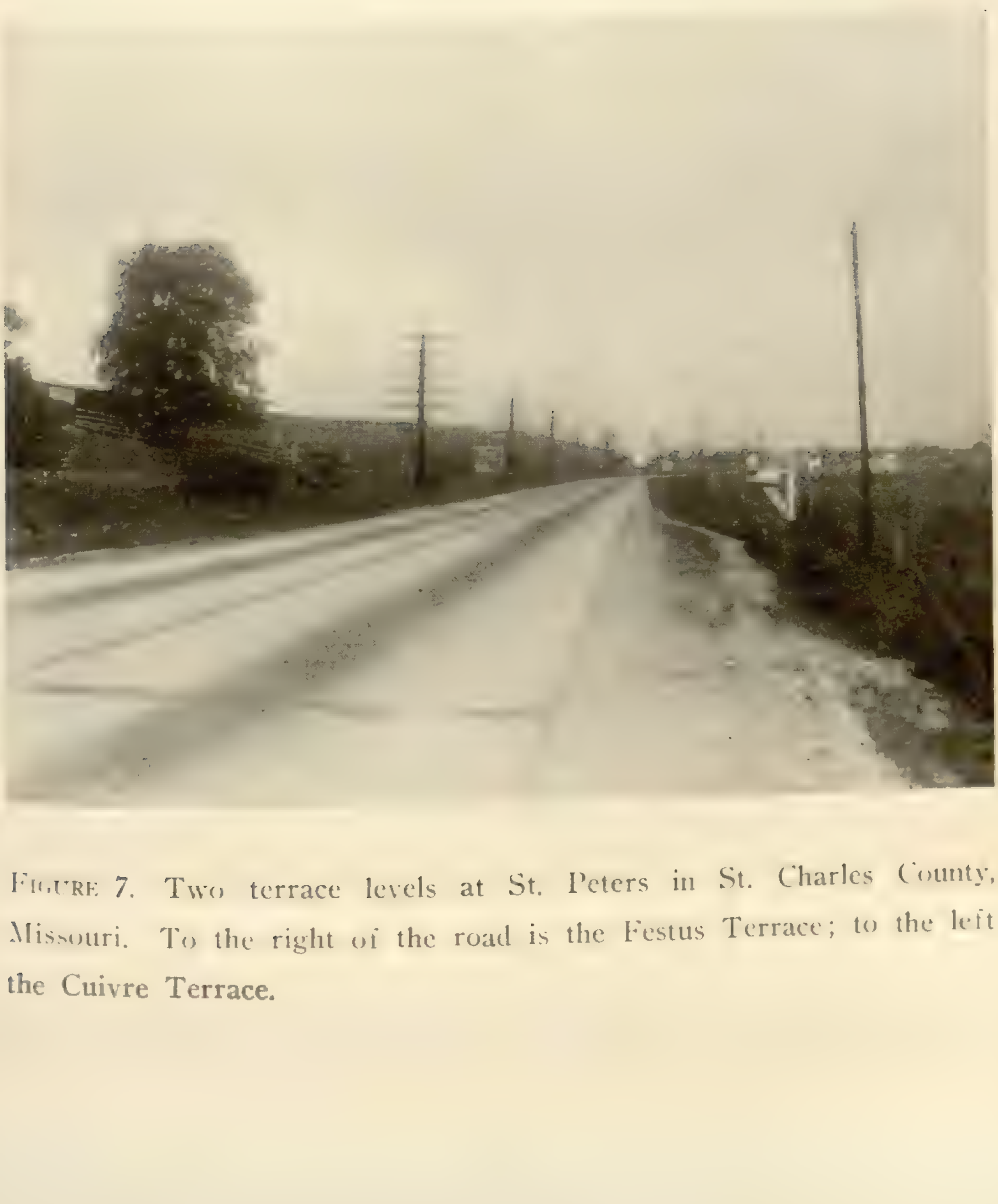


FIGURE 7. Two terrace levels at St. Peters in St. Charles County, Missouri. To the right of the road is the Festus Terrace; to the left the Cuivre Terrace.

belt two to eight miles in width. The flatness of the surface is clearly shown in Figure 8.

The Cuivre River has intrenched itself in this terrace forming a cut through it, 40 feet or more in depth and nearly a quarter of a mile in length, just south of Chain-of-Rocks, Lincoln County, Missouri (Fig. 9). The village is in Lincoln County; but since the Cuivre River is here a boundary line, the cut is really in Cuivre township, St. Charles County. This Chain-of-Rocks should not be confused with the better known locality of the same name on the Mississippi River at the northern end of St. Louis. For the locality on the Cuivre River the expression Chain-of-Rocks, Lincoln County, will be used; for the other locality, Chain-of-Rocks, St. Louis.

A vertical section was measured a short distance south of Chain-of-Rocks, Lincoln County, and is shown in Table II. The terrace is composed of layers of rather fine sand, silt and clay. These strata are on the average approximately three feet in thickness and none is less than one foot. Wherever the terrace has been examined, relatively thick layers similar to these have been observed. Due to the excellence of the exposure in Cuivre township, St. Charles County, the name Cuivre Terrace is assigned to the terrace.

In addition to the extensive distribution of the Cuivre Terrace along the great bend of the Mississippi above Grafton, the terrace can be traced in many other localities. Within the limits of the Middle Mississippi River Region it is exposed over great areas along Wood River, Illinois, and in the flat extending southward to the vicinity of Cahokia Creek, north of Edwardsville, Madison County, Illinois. In this part of the terrace the stratified nature of the alluvium, for about 40 feet below the surface, is clearly shown in various cuts. In some places the alluvium is covered by more or less loess. Two erratics were discovered in the alluvial material. A well-rounded cobble of pink granite, weighing about ten pounds, was picked out of the side of

FIGURE 8. Limestone-cored hills rising above the flat surface of the Cuivre Terrace a short distance east of Moscow Mills, Lincoln County, Missouri.

FIGURE 9. A section of the Cuivre Terrace along the Cuivre River south of Chain-of-Rocks, Lincoln County, Missouri.

4 feet	Reddish clay, sticky when wet.
3 feet	Sand, medium grained.
2 feet	Reddish clay, sticky when wet.
3 feet	Silt.
1 foot	Fine yellow sand with few small pebbles.
4 feet	Yellow silt.
2 feet	Hard reddish clay.
5 feet	Buff-colored, fine sand.
3 feet	Gray clay.
2 feet	Fine sand containing pipe-stem concretions.
8 feet	Gray clayey silt.
	Base covered.

TABLE II.

Section of "Cuivre Terrace" on Cuivre River, St. Charles County, a short distance south of the village of Chain-of-Rocks, Lincoln County, Missouri. This section is shown in Figure 9.

a road cut about half way between Wanda and Oak Grove School in Madison County, Illinois. An irregular slab of red limestone, about 15 inches across and 4 inches thick, containing a considerable quantity of dark-colored chert, was discovered a short distance north of Oak Grove School in a road cut.

Piasa Creek valley in Jersey County, Illinois, exhibits two terraces, the upper of which can be recognized as part of the Cuivre Terrace. Small patches of sand caught in low notches in the bluffs a short distance from Elsah, Jersey County, Illinois, can be similarly correlated.

In the northern part of St. Louis County there is a small tributary which empties into the Mississippi, half way between Fort Bellefountaine and Halls Ferry. This tributary has eroded several steep banks which show the same thick strata of alternating sand and clayey silt. In addition to the usual succession here, at the very top of the terrace there is about six feet of very thinly laminated silt, each layer less than an inch in thickness, the partings between the laminae showing paper-thin layers of brown ferruginous material (Fig. 10). The laminae strongly suggest seasonal accumulations. They have also been found beyond the area under consideration.

Cuivre Terrace cannot be traced in any tributary of the Mississippi on either side of the river south of the mouth of the Missouri River. It appears to stop abruptly and cannot be correlated satisfactorily with any terrace farther south.

This terrace may be traced in the tributaries of the Missouri River from Femme Osage Creek in St. Charles County westward, certainly as far as Frene Creek, near Herman, Gasconade County, Missouri, which is as far west as the study has been carried. The relatively thick strata of the terrace is well seen along Labadie Creek just north of Labadie, Franklin County, Missouri (Fig 11). The sand layers are usually less common than the silt, and with the increase in quantity of the stratified loess-like silt, it is easy to see how early investigators were inclined

FIGURE 10. Thinly laminated strata at the top of the Cuivre Terrace in the unnamed creek halfway between Fort Bellefountaine and Halls Ferry in the northern part of St. Louis County.

FIGURE 11. Stratified loess-like silt in a cut along Labadie Creek a short distance north of Labadie, Franklin County, Missouri. This is a part of the Cuivre Terrace.

to believe that the loess was a water-laid deposit. These stratified deposits resemble the true loess of the uplands very closely, differing only, at least megascopically, in the presence of stratification and in complete freedom from land shells. Similar "stratified loess" may be seen south of Gumbo, Franklin County, where Wildhorse Creek Road crosses Caulks Creek. It is also clearly developed along DuBoise Creek, east of Washington, Franklin County, Missouri.

Layers of sand are less frequently encountered than are layers of silt. But a lenticular-shaped bed of sand may be seen in a road cut on Missouri Highway 94, east of New Haven, Franklin County, at an elevation of 508 feet, which is characteristic of this terrace. A layer of sand has been excavated for a sand pit on Wildhorse Creek Road, a short distance west of Chesterfield, Franklin County. This sand is undoubtedly a part of the Cuivre Terrace.

No erratics have been observed in the Cuivre Terrace along the Mississippi or Missouri rivers, except in the vicinity of Oak Grove School in Madison County, Illinois, previously described.

The highest elevations found on the Cuivre Terrace do not exceed 530 feet. It is possible that the actual alluvial deposit does not quite reach this elevation. The alluvium may be covered with some loess. The lowest elevations recorded are 480 feet. But in all cases where the elevation is less than 510 feet there has been ample opportunity for widespread erosion to have removed a considerable portion of the terrace. The uneroded surfaces lie at elevations between 510 and 530 feet.

The wide distribution of the terrace above St. Louis, its absence below St. Louis, the uniformly fine character of the sediments, the finely laminated top layers found in a few localities, and the quite uniform elevation of the initial surface, all indicate that the Cuivre Terrace was deposited in a lake which filled the Mississippi valley north of St. Louis to an elevation of about 530 feet.

THE BOEUF TERRACE

Westward from Oetters (a station on the Chicago, Rock Island and Pacific Railroad east of Labadie, Franklin County, Missouri) a much eroded terrace, 35 feet or more above the Cuivre Terrace, occurs with considerable regularity. The terrace is much more dissected than is the Cuivre Terrace. A section of this higher terrace may be observed along a road cut on Missouri Highway 94 in the vicinity of Big Berger Creek, in Boeuf township, Franklin County, Missouri, as well as in several other creek valleys in Boeuf township and elsewhere (Fig. 12). The name Boeuf Terrace is tentatively assigned to this terrace displayed along the Missouri River above the Cuivre Terrace and particularly in Boeuf township.

The terrace is composed of a loess-like silt and does not show conspicuous stratification in any of the cuts thus far observed. It contains rather numerous erratics which occur in the midst of apparently unstratified silt. Several cobbles of undoubted northern origin were found on the surface of the terrace at Big Berger Creek. A rounded boulder of light pink granite, more than 18 inches in one dimension, may be seen in the unstratified silt at Oetters (Fig. 13). Several other such erratics have been found on the south side of the Missouri between Oetters and Hermann. Thus far no erratics have been discovered on the north side of the Missouri River, although the terrace is well developed there.

It may be desirable to interpolate here a brief explanation to account for the presence of erratics. Ice-rafting seems the most plausible explanation. A study of maps showing various ice fronts makes it evident that the Nebraskan, Kansan, and Wisconsin ice sheets all crossed the course of the Missouri above Hermann, and also that the Kansan ice sheet stood essentially parallel to the Missouri River not more than a few miles to the north of it in this vicinity (Fig. 14). If the terrace had been formed in Wisconsin time, all previous terraces would probably have been covered. Moreover, the dissection of the Boeuf Ter-

FIGURE 12. Boeuf Terrace overlying residual mantle rock at Big Berger Creek in Franklin County, Missouri, exposed by a road cut along Missouri highway 94.

FIGURE 13. Pink granite boulder in a silt deposit west of Oetters, Franklin County, Missouri. It is in the Boeuf Terrace and was probably carried to its present location by ice-rafting.

Figure 14 Map showing the extent of the Pleistocene ice scheets near the Middle Mississippi River Region, according to Antevs, Bulletin of the Geological Society of America Vol. 40 N. Nebraskan, K. Kansan, I. Illinoisan, W. Wisconsin Ice Sheets.

race is more mature than is that of the Cuivre or any other terrace studied in his region. It thus appears that the Boeuf Terrace antedates all the other and can hardly be attributed to material from the Wisconsin ice sheet. So it would seem that the Boeuf Terrace is associated with either the Nebraskan or the Kansan ice sheet. The presence of numerous erratics makes it appear that correaltion with the Kansan ice sheet, whose front was parallel to the Missouri River in this vicinity, is more probable than correlation with the Nebraskan.

Although the terrace may be traced in tributaries of the Missouri on both sides of the river from Oetters to Hermann, careful search has failed to reveal the presence of a terrace of this description anywhere east of Oetters along the Missouri River or anywhere at all along the Mississippi River as far north as the study has gone; namely, to Winfield. Either the terrace has been entirely removed in these localities, or it never was formed there. Evidence seems to favor these later alternative. In several places limestone-cored hills project through the Cuivre Terrace. If the Boeuf Terrace existed at such points, it would almost certainly appear; but it does not. Figure 8 shows such a situation.

The Boeuf Terrace seems to have been formed in a lake formed by the damming of the Missouri River. The presence of numerous erratics indicates that some ice front, probably the Kansan, formed the border of part of the lake. It seems likely that the ponding of the water was due to an ice dam which crossed the Missouri River. The lake in which the terrace was formed must have had an elevation of at least 570 feet. Leverett[4] once made the suggestion that the Missouri River once might have flowed into the valley of of the Meramec in the vicinity of Grays Summit during the Nebraskan age. Since the lowest col in the bed rock at Grays Summit has an elevation higher than 650 feet, it hardly seems likely that the waters from the lake that formed the Boeuf Terrace escaped at that point. The outlet for the lake has not yet been discovered and it may have been through or under the ice itself, as Chamberlain[5] suggested in the case of an ice dam on the Ohio River.

MISCELLANEOUS TERRACES IN ILLINOIS SOUTH OF ST. LOUIS

Several streams on the Illinois side of the Mississippi River south of St. Louis exhibit, in addition to the Festus Terrace, other terraces. In each of the streams, where they have been observed, they have approximately the same gradient as the stream with which they are associated. These stream terraces seem to be quite independent of one another. Their elevations at their mouths are not found to be concordant. The terraces appear to have been developed in each tributary individually when the waters of the tributary were receiving greater volumes of sediment than they are at the present. Such a terrace was studied in the lower portion of the Kaskaskia River and it seems probable that further study would show that the terrace continued for a considerable distance upstream. Clear Creek, Union County, Illinois, also has such a terrace. Several other tributaries of the Mississippi River on the Illinois side display two terrace levels near their mouths, one of which can be correlated to the Festus Terrace; but not the other, which is regularly higher than the Festus Terrace.

Time was not available to give this set of terraces much detailed study, but it seems to be established that each stream developed its own terrace, uninfluenced by adjacent streams, and that each terrace appears to have its own gradient and its own summit level. These terraces are not, then, fragments of a single flood plain, as is the case of the Festus Terrace; but they are rather a group of terraces, of which the one along the Kaskaskia River may be taken as a type.

TERRACE SUMMARY

There are three extensive terraces that can be observed in the Middle Mississippi River Region.

1. The Festus Terrace, a former flood plain whose remnants may be traced on both sides of the Mississippi from Cape

Girardeau to a point north of St. Louis. It is characterized by a surface slope of four inches per mile, which is considerably less than that of the Mississippi River at the present time. It is stratified and is composed of thin layers of loess-like silt, fine sand, and some fine gravel.

2. The Cuivre Terrace, whose upper surface is so remarkably level over considerable distances as to make it appear to be a lake terrace. It is characterized by thick strata of loess-like silt and some sand. The terrace has wide expanses north, but not south, of St. Louis.

3. The Boeuf Terrace, which is characterized by the presence of glacial erratics in the midst of unstratified silt. It has been highly eroded. It can be traced along the Missouri River, from a point a short distance east of Labadie, westward; but not eastward, nor along the Mississippi River. It appears to be a terrace formed in a lake like the Cuivre Terrace, but at an earlier time.

In addition, there is a group of terraces, of which the one on the Kaskaskia River may be considered a type. They are individual and independent terraces, found only on the Illinois side of the river and south of St. Louis.

THE DRIFT

General Statement

The drift in the Mississippi Basin has long been the subject of careful investigation by numerous geologists. It would appear that the first published reference to drift within the Middle Mississippi River Region was by Worthen[6]. He referred to a glacial blue clay 12 feet thick found at the corner of West Pine Boulevard and Taylor Avenue and for several blocks westward in St. Louis. Among others who, during the nineteenth century, recognized glacial till in the Middle Mississippi River Region

may be mentioned Wright,[7] Wheeler,[8] and Todd.[9] The climax of the work on the drift in this region during the nineteenth century came with the publication in 1899 of Leverett's[10] extensive monograph on the Illinoian ice lobe. His work clearly established the location of the former border of the ice of the Illinoian Age in Illinois. Drushell,[11] in 1908, and again in 1911, called attention to numerous exposures of drift in St. Louis, including an excellent exposure at Chain-of-Rocks, St. Louis. Radebaugh[12] made a study of the drift in the northern part of St. Louis and St. Louis County. Many others have examined the drifts in the Middle Mississippi River Region, especially in the vicinity of St. Louis, where the evidence is rather abundant and the situation critical. Practically all that remained for the present writer was to re-examine previously described exposures and observe some new cuts that were not made at the time of the earlier workers.

Pebble counts have been made of the drift at critical spots. Samples of drift were collected and studied in the laboratory. These were taken in the field by cleaning the surface of the drift from possible contamination, using, insofar as possible, a place where a section of the drift was exposed that would permit vertical sampling. Samples, weighing from ten to twenty pounds, were collected from the cleaned surface of the drift, particular care being taken not to select pebbles simply because they had a conspicuous appearance. Everything was taken from the surface for a depth of as many inches as was necessary to collect a sample containing not less than 400 pebbles.

These samples were then analyzed in the laboratory by a method similar to the one suggested by MacClintock.[13] The samples collected in the field were screened. All pebbles that would not pass through a half-inch screen were retained for analysis. In addition to this, all the pebbles retained by the quarter-inch screen were set aside and a sufficient number of these added to those retained by the half-inch screen to make a total number of pebbles not less than 400. Coning and quartering was resorted to in order to select the proper number of

smaller pebbles to bring the total number to 400. In some instances a far larger number of pebbles was analyzed, from a single exposure, and in one instance, where only a small quantity of drift was secured, the number of pebbles was less than 400. Every effort was made to avoid personal selection. These pebbles were cracked and the fresh surfaces examined under the binocular microscope. Dilute hydrochloric acid was used to identify limestone, and hot hydrochloric acid to identify the finely broken dolomite. The results of several pebble counts, using this method, are shown in Table III.

Since some of the samples of Illinoian drift came from exposures from which the calcareous material had been leached and other samples did not, it seemed desirable to disregard all calacareous and dolomitic pebbles in calculating the percent of northern pebbles present in the sample. This gave a result which might be described as the per cent of northern pebbles among the total insoluble pebbles, the word insoluble referring to those insoluble in hydrochloric acid. This percentage was obtained by dividing the sum of the igneous and metamorphic pebbles by the total number of pebbles after the limestone and dolomite pebbles had been subtracted. The results of these analyses may be epitomized as follows:

Per cent of foreign pebbles among the insoluble pebbles

	Maximum	*Minimum*	*Average*
Pre-Illinoian	13.6%	1.9%	5.9%
Illinoian	36.8%	17.1%	24.6%
Wisconsin (one only)	49.6%	49.6%	49.6%

From this data it appears possible to differentiate pre-Illinoian drift from Illinoian drift in this locality on the basis of the percent of northern pebbles among the insoluble ones. Pre-Illinioan drift carries less than 15 per cent foreign pebbles. among the insoluble ones; Illinoian drift, 15 per cent or more. But comparison of these analyses with those MacClintock made

on pre-Illinoian drift in Illinois fails to reveal any similarity between the pre-Illinoian drift from the vicinity of St. Louis and either the Kansan or Nebraskan drift of Illinois.

In all cases, the per cent of foreign pebbles among the insoluble ones in the pre-Illinoian drift in and near St. Louis is considerably lower than the per cent of foreign pebbles, if based on the insoluble ones, found by MacClintock in either Kansan or Nebraskan drift in Illinois. On this basis it would appear probable that the pre-Illinoian drift of St. Louis and vicinity is not from the same ice sheet that produced either the Kansan or Nebraskan drift that MacClintock studied in Illinois.

For future work an improvement on the method of analysis it is recommended, namely to divide the quartzite pebbles into two groups, reddish ones similar to either Sioux or Baraboo quartzite, and all others. It is apparently impossible to distinguish between the Sioux and Baraboo quartzites; so in this study, when either name is used, it is intended to refer to the reddish, pinkish, or purplish quartzite which is highly silicified and usually conspicuously banded, that is found in the neighborhoods of Baraboo, Wisconsin, and Sioux Falls, South Dakota. While it is recognized that pebbles of quartzite of quite similar appearance are found in Labradorean drift sheets occasionally, they are not usually as common nor as large as the cobbles and boulders of this very resistant and characteristically colored quartzite in the Kewatin drift, especially near St. Louis.

In every instance where the evidence in the field made it clear that the drift was Illinoian or pre-Illinoian, the pebble analysis completely agreed with the field observation. There were several instances in which the field evidence was not conclusive. In these cases, the pebble analysis fell so far on one side or the other of 15 per cent, which seems to be the point of demarcation between the Illinoian and pre-Illinoian tills, that the identification of the drift was clear. It is to be hoped that some satisfactory method of distinguishing between Kansan and

TABLE III. ANALYSIS OF DRIFT BY PEBBLE COUNT

Key to localities mentioned in following table.

A	Taylor Ave. and Papin St., St. Louis.
B	Eastern end of Forest Park, St. Louis.
C	Delor and Minnesota Aves., St. Louis.
D	Creek one mile north of Watkins Creek in St. Louis, Co.
E	O'Fallon Park, St. Louis,
F	West of Chain-of-Rocks Bridge and more than fifty feet above Riverview Drive, St. Louis.
G	Watkins Creek, about a mile west of Chain-of-Rocks Park, St. Louis.
H	U. S. Highway 66 and the St. Louis-St. Louis County boundary line.
I	West of Chain-of-Rocks Bridge, about ten feet above Riverview Drive, St. Louis.
J	U. S. Highway 66 at Columbia Bottoms Road at curb level, St. Louis.
K	One-half mile west of Chain-of-Rocks Park, St. Louis.
L	Opposite Elm Branch School, St. Charles County, Missouri.
M	Jersey County, Illinois, at U. S. Highway 67 and Illinois State Highway 109.
N	Little Sandy Creek, near Winchester in Scott County, Illinois. Illinoian drift from the top of the exposure.

TABLE III.—Continued

Localities, previous page gives key to these.

Varieties	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Sedimentary														
Chert	499	290	62	841	156	202	247	475	268	1033	474	40	285	89
Limestone	----	----	----	----	84	----	----	----	----	----	----	246	----	206
Dolomite	----	----	----	----	----	----	----	----	----	----	----	80	----	115
Sandstone	119	81	129	60	21	34	8	4	33	10	45	12	129	18
Vein quartz	41	16	1	138	58	35	5	32	63	144	56	4	31	29
Shale	11	44	----	----	9	----	3	4	----	----	----	----	2	13
Limonite*	7	32	----	----	----	----	----	----	----	----	----	----	----	----
Arkose, etc.	----	----	----	----	1	----	----	----	20‡	----	----	----	1	1‡
Total	677	463	192	1039	329	271	263	515	384	1187	575	382	448	471
Igneous														
Basalt	22	----	1	----	----	42	----	2	8	----	3	12	4	8
Diorite	1	----	----	----	----	6	----	----	2	----	----	8	----	2
Gabbro	----	----	----	----	----	2	----	----	----	----	----	5	----	----
Dolerite	1	28	6	6	26	2	----	----	----	----	2	----	----	----
Dunite	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Felsite	----	----	----	----	----	----	----	----	10	----	----	----	----	4
Rhyolite	3	2	----	1	1	26	----	----	7	----	----	----	----	----
Grainte†	17	18	4	74	23	41	----	6	53	6	4	24	11	11
Amygdaloid	----	1	----	----	----	----	----	----	----	----	----	----	----	----
Total	44	49	11	81	50	119	0	8	80	6	9	49	15	25
Metamorphic														
Quartzite	13	23	2	11	24	35	4	4	18	2	10	3	4	5
Gneiss	1	1	----	----	----	3	----	----	5	----	1	3	----	----
Schist	----	----	----	1	1	1	----	----	----	----	----	----	----	1
Hematite	----	----	----	1	----	----	----	----	----	----	----	----	----	----
Slate	----	----	----	----	----	----	1	----	----	----	----	----	----	----
Total	14	24	2	13	25	39	5	4	23	2	11	6	4	6
Grand Total	735	536	205	1133	404	429	268	527	487	1195	595	437	467	502
% foreign pebbles based on insoluble ones	7.8	13.6	6.5	8.3	23.4	36.8	1.9	2.3	21.2	0.7	3.5	49.6	4.1	17.1

*Limonite probably pesudomorph after pyrite. †Including individual feldspar grains. ‡Greywacke.

Nebraskan till can be developed. The single sample of drift that was believed to be of Wisconsin age was collected in St. Charles County, Missouri, in a unique position and showed a marked variation in composition from either the Illinoian or the pre-Illinoian samples. It is referred to later.

THE WISCONSIN DRIFT

The nearest approach of the Wisconsin ice sheet to the Middle Mississippi River Region was in the vicinity of Peoria, Illinois, which is approximately 100 miles from the northern boundary of the region. A tongue of ice from the Iowa ice sheet, which is now classified as the earliest sub-stage of the Wisconsin, crossed the Mississippi River a short distance north of Davenport, Iowa. This point is about 250 miles north of the northern boundary of the region. It may be seen that the effects the Wisconsin ice sheet would have had on the region would have been only indirect, through water-transported material.

THE ILLINOIAN DRIFT IN ILLINOIS

The writer has re-examined the till in the Middle Mississippi River Region. The probable location of the various ice fronts near St. Louis is shown in Figure 14. At Edwardsville, Madison County, Illinois, a section of the drift is well exposed in the overburden of the shale-pit of the Alton Brick Company. This section is shown in Table IV. Particular attention is called to the stratified character of the upper ten feet of the drift.

From Edwardsville northwestward, the elevation of the surface on which the drift rests decreases and the thickness of the drift also decreases. About four miles northwest of Edwardsville, near Wanda, a glacial gravel characteristic of a frontal apron, or outwash plain, can be observed at an elevation of 430 feet. From Wanda to Alton no drift was observed in any cuts; but in several localities sand and some deposits of blue clay appear to have been formed by water transporation from the drift.

25-30 feet	**Loess, buff to gray.**
3 feet	**Brown till.**
1 foot	**Stratified silt.**
6 feet	**Mottled brown till, showing imperfect stratification; elevation of base is 480 feet.**
30 feet	**Gray till.**
	Base of drift at 450 feet.
	Pennsylvanian shale base unexposed.

TABLE IV
Section of drift in the Alton Brick Company shale pit at Edwardsville, Madison County, Illinois.

The drift may be traced in a broad arc, convex to the northeast, to a point about half way between Bethalto and East Alton, both in Madison County, Illinois. From here a slightly irregular line can be drawn to the conspicuous drift on Otter Creek, Jersey County, Illinois. The drift along this line is largely covered by loess, but may be traced by a succession of low, broad, inconspicuous mounds and by exposures of drift in some cuts.

Southward from Edwardsville, the drift may be seen not far from the Mississippi bluffs to Caseyville, St. Clair County, Illinois. From here southward the boundary of the drift has not been re-examined. Leverett's work indicates that the ice front stood approximately parallel to the present bluffs of the Mississippi River, but some distance east of them as far south as Murphysboro, Jackson County, Illinois, were it turned eastward beyond the limits of the Middle Mississippi River Region.

On the flood plain of the Mississippi River, west of Caseyville, there is a group of low, conical hills, most of them scarcely reaching a height of 40 feet above the flood plain. The highest one, known as Cahokia Mound or Monks Mound, reaches an elevation approximately 100 feet above the flood plain. These mounds are commonly called Indian Mounds. It has been been supposed that they were constructed by human agency. It is certain that some, but apparently not all, of the mounds were used by some early pre-white inhabitants as burial sites. Probably all would agree that the upper portion of Cahokia Mound is of artificial construction. Worthen[14] held that the base of this mound, was made of drift clay and was natural. Others have disagreed with him. The writer has no additional comment save this, if they are of drift clay and natural, their location is most significant, being directly in line with the drift at Caseyville and at O'Fallon Park, St. Louis.

THE ILLINOIAN DRIFT IN ST. LOUIS AND ST. LOUIS COUNTY

A thin strip of ice-laid drift may be traced, with some interruptions, for a distance of about eight miles along the bluffs

of the Mississippi River on the Missouri side. In no place can it be shown that the strip is more than a mile in width and it may be no more than a few hundred feet in some places.

The northern end of the exposure is along cuts made by an unnamed creek two miles north of the pump house of the St. Louis City Water Works at Chain-of-Rocks, St. Louis. (This locality should not be confused with the village of Chain-of-Rocks, Lincoln County, which is referred to elsewhere in this report.) Here the Illinoian drift is of gray to brown colored, stiff clay, containing numerous pebbles. One boulder may be seen protruding from the clay about 20 feet above the stream. Another larger boulder, weighing more than a ton, of red granite porphyry lies in the creek bed below the drift. A photograph taken several years ago shows this boulder came from the Illinoian drift.

From the exposure in the unnamed creek, just described, to a point about half a mile south of the settling basins of the St. Louis City Water Works, the drift is mantled by loess, but can be traced by numerous cuts across it. In much of this distance the drift resembles that in the cut in the unnamed creek two miles to the north. In Chain-of-Rocks Park, opposite the City Water Works, and for a short distance northward, much of the drift is waterlaid. A thickness of 40 feet of sand and gravel has been reported.

U. S. Highway 66 crosses the glacio-fluvial deposit in this vicinity and a cut at the boundary between St. Louis and St. Louis County. (Table V). There is some question as to the age of this drift. It may be in part water-laid pre-Illinoian, but the bulk of the evidence favors its being water-laid Illinoian.

In a small cut about a hundred yards north of the western end of the Chain-of-Rocks bridge there is an exposure of gravel. The gravel is 20 feet or more in thickness, apparently water-

1 foot	**Elevation of top 508 feet. Soil.**
12 feet	**Loess, buff colored and somewhat leached.**
9 feet	**Loess, buff colored, unleached and with numerous calcareous concretions.**
7 feet	**Drift, apparently water-sorted, brown clay above, grading downward into brown sand.**
1 foot	**Gravel, rather coarse.**
4 feet	**Brown sand.**
10 feet	**Gray clay, probably altered Pennsylvanian shale.**
	Base, Pennsylvanian shale.

TABLE V.

Section of drift partly water-laid, at U. S. Highway 66 and the St. Louis-St. Louis County boundary.

laid, interspersed with beds of sand and composed principally of chert pebbles (Fig. 15 and Table VI).

It may be that the glacier has incorporated some Lafayette gravel with the drift. The Lafayette gravel occurs in a characteristic way within a few miles of this locality. It might be added that the Lafayette gravel is composed of almost, but not quite exclusively, of rounded pebbles of chert, quartz, and quartzite, together with sand.

About a mile west of the place just described, Watkins Creek has undercut its bank and exposed a section of drift 17 feet thick overlaid by 36 feet of loess (Fig. 16). A part of this drift is also stratified. A large number of reddish purple quartzite boulders are found in the stream, which leads to the supposition that this might be pre-Illinoian drift (Fig. 17). The Kansan drift of Lincoln County, Missouri, has many such boulders. But it is highly probable that these boulders are from reworked Lafayette gravel as previously suggested.

From one-half mile south of the settling basins of the St. Louis City Water Works to O'Fallon Park, for a distance of four miles, no drift appears. In the northern portion of this section, near Prospect Hill, the Missouri Portland Cement Co. has excavated a large pit in the Pennsylvanian shale. In the face of the overburden no drift may be seen. A very few pebbles of northern origin were picked up; but it would seem clear that no ice-laid deposit was made here. There is, however, meager circumstantial evidence that drift underlies both Calvary and Bellefontaine Cemeteries.

In O'Fallon Park steep gullies expose at least 50 feet of till covered by about 20 feet of loess. The drift is of a light buff to gray color, clay-like, with numerous small pebbles and not a few limestone erratics exceeding two feet in diameter. The drift has been leached and in certain layers calcareous con-

FIGURE 15. Gravel of glacio-fluvial origin, composed principally of chert pebbles near Chain-of-Rocks, St. Louis.

36 feet	**Elevation of top 480 feet.** **Loess, buff colored.**
6 feet	**Brown boulder clay, sandy above, grading into stiff clay below.**
1 foot	**Brown, coarse sand, containing small pebbles. Surface highly cemented.**
10 feet	**Stiff clay, pebbly above, grading into yellowish sandy gravel below.**
½ foot	**Pennsylvanian shale.**
1½ feet	**Pennsylvanian coal.**
	Elevation of stream 425 feet.

TABLE VI.

Section exposed on Watkins Creek, a few hundred yards south of U. S. Highway 66 and about a mile west of Riverview Drive.

FIGURE 16. Drift on Watkins Creek a few hundred yards south of U. S. highway 66 and about a mile west of Chain-of-Rocks, St. Louis. This is the same section as shown in Table VI. This may be of pre-Illinoian age, or it may be Illinoian drift intermingled with Lafayette gravel.

FIGURE 17. Numerous boulders principally of quartzite in the bed of Watkins Creek about a mile west of Chain-of-Rocks, St. Louis. Most of the boulders are about a foot in diameter and resemble the Baraboo quartzite closely.

cretions like the loess-menschen are found. This appears to be the thickest and most extensive deposit of typical Illinoian till in St. Louis or St. Louis County.

The general character of the till, from north of Chain-of-Rocks to O'Fallon Park, has caused every investigator, including the present one, to correlate it with the Illinoian drift directly across the river. Studies of the position of this ice front in Madison and St. Clair Counties, Illinois, indicate that this drift is closely associated with that found between Edwardsville and Caseyville. Pebble analyses are clearly in accord with this view.

PRE-ILLINOIAN DRIFT IN ILLINOIS

Bell and Leighton[15] have reported pre-Illinoian drift in several localities in Illinois, including, a particularly significant one in the vicinity of Winchester, where two different stream-cut banks expose three successive layers of till, proving beyond doubt the existence of both Nebraskan and Kansan till in Illinois. The writer visited the spot, sampled and photographed the exposure on Little Sandy Creek (Fig. 18). The top of the oldest till is highly altered, but it is recognizable as till.

MacClintock[16] sampled and made pebble analyses of the pre-Illinoian drift from many localities in Illinois, and came to the conclusion that the Kansan drift was from the Labradorean center and the Nebraskan drift from the Kewatin center. In a map in his article, he indicated that it was his opinion that a pre-Illinoian drift found in St. Louis is of Kansan age from the Labradorean center. Analyses made in this study are not in accord with this opinon, but indicate a Kewatin source.

In 1921, Leighton[17] described a drift deposit in the quarries in the Mississippi River bluffs at Alton, Illinois. He described the drift as from one to three feet in thickness, considerably weathered, and containing calcareous concretions in which earlier investigators had found several mamalian fossil frag-

FIGURE 18. Nebraskan, Kansan, and Illinoian till on Little Sandy Creek about ten miles south of Winchester, Scott County, Illinois.

ments. Overlying the drift there was loess which Leighton believed to have been deposited probably at two different stages, presumably the Sangamon and Peorian. Leighton recognized that it was possible that the drift was of Illinoian age, but was inclined to consider it of earlier origin, and suggested that it might be of Kansan age.

In 1923, Leverett[18] presented data before the Geological Society of America which had led him to the conclusion that the Nebraskan ice front in Illinois extended some distance beyond the Illinoian ice front. Some of the evidence was based upon the presence of erratics at positions that would be impossible to ascribe to ice-rafting or any means of transportation except ice. The drift itself, he believed, had been removed during the very lengthy post-Nebraskan time. Leverett[19] reiterated this idea in 1924, and in a letter to the writer, dated March 25, 1936, indicated that he still retains the belief.

The writer reexamined the drift in the quarry of the Illinois Sand and Materials Company at Alton, described by Leighton (Fig. 19). It seems to be far more weathered than the Illinoian till only a few miles away.

Erratic cobbles and pebbles have been observed in several places along the Mississippi River bluffs in Jersey County, Illinois, specifically at Elsah and Grafton. From the location of these pebbles and cobbles it is questionable if they were transported to their present location by streams from the Illinoian ice border. And their location is such as to make ice-rafting most improbable.

PRE-ILLINOIAN DRIFT IN LINCOLN AND ST. CHARLES COUNTIES AND THE IMMEDIATE VICINITY

Drift of Kansan age is found in considerable quantities in Lincoln County, Missouri. The coarse glacial deposit in the

FIGURE 19. General view of the quarry of the Illinois Sand and Materials Company at Alton, Illinois, showing six feet of drift of possible pre-Illinoian age overlying the limestone and in turn overlaid by loess.

Mississippi bottoms near Winfield, Missouri, has been used for commercial gravel pits. This gravel is probably a derivative from Kansan drift. Leverett[20] and Rubey[21] both state that in the vicinity of Batchtown, Calhoun County, Illinois, there is drift of Kansan age which should probably be correlated with the drift across the Mississippi River in Lincoln County. It would appear that the ice sheet crossed the present valley of the Mississippi in that vicinity. From personal observation, it appears that the Kansan drift continues southward from Winfield into St. Charles County. A thin layer of drift containing some large boulders can be traced along Missouri Highway 79 to within two miles north of O'Fallon, St. Charles County, Missouri. The boulders include one of basalt, conspicuously striated and over a foot in diameter, and a boulder of Baraboo quartzite, whose dimensions exceed three feet. It would appear from Leverett's studies, as shown in Antev's[22] maps, (Fig. 14), that the Kansan ice front stood essentially parallel to the Missouri River, but several miles north of it, in St. Charles or Lincoln counties, and for some distance westward.

North of St. Charles a thickness of more than 20 feet of fine clay, very uniform in texture, is exposed in a cut of the Wabash Railroad. The upper ten feet of the clay is mottled brown and gray, but below this the clay is of a deep blue color. The elevation of the upper surface of the clay is 540 feet. Similar blue clay, at a lower elevation, may be found in Elm Branch Creek, a northward flowing stream near Elm Point, St. Charles County. The clay closely resembles the sort laid down in quiet pools adjacent to an ice front.

In a tributary to Elm Branch Creek, on a farm owned by J. H. Ludwig, a portion of a mastodon skeleton was excavated in 1935. The bones were found in the blue clay just referred to. Most of the skull, with the teeth, fragments of the tusks, and several bones, all in a bad state of decomposition, were excavated and placed in the collections of the Department of Geology and Geography at Washington University.

Very similar blue clay has been found in a creek just south of Halls Ferry and in the bed of a nameless creek half way between Halls Ferry and Fort Bellefontaine, both in north St. Louis County.

Just across the Missouri River from St. Charles County numerous boulders have been reported by various investigators. Fenneman[23] reported glacial gravel at the mouth of Feefee Creek. Shipton,[24] Bridge,[25] and Hanley,[26] found large boulders of quartzite and crystalline rock, which are represented by samples in the collections of the Department of Geology and Geography at Washington University. Charles Bishop, an experienced quarryman with the Stone Ridge Quarry near Vigus, Misouri, told the writer several granite boulders over a foot in diameter were removed with the overburden of the quarry. The elevation of the location he pointed out is about 500 feet. The writer found stratified sediments in a tributary of Feefee Creek and a granite cobble in the vicinty of Vigus.

On the basis of the evidence of drift in Lincoln and St. Charles Counties, of blue clay near St. Charles, and of a considerable accumulation of boulders and glacial gravel across the Missouri River from St. Charles, it would seem probable that the Kansan ice front crossed the Missouri River in this vicinity.

PRE-ILLINOIAN DRIFT IN ST. LOUIS AND NORTH ST. LOUIS COUNTY

In St. Louis and St. Louis County there is evidence that ice of definitely pre-Illinoian age once existed. The writer has reexamined many localities reported by Drushell and others where the drift is still exposed. Many of the exposures of drift have been covered or obliterated by building operations. The construction, during the winter of 1935-36, of the new superhighway across Forest Park and eastward, exposed a practically continuous deposit of drift from the eastern end of Forest Park

and for several blocks east therefrom, but not westward (Figs. 20 and 21). L. M. Dougan, Principal of the Eugene Field Public School, called the writer's attention to an excavation being made at the Corner of Taylor Avenue and Olive Street. This excavation showed the presence of pre-Illinoian drift.

It has been possible to interview some individuals who saw the relatively recent excavations for the United States Postoffice at Market and Eighteenth streets, and for the Southwestern Bell Telephone Building at Pine and Eleventh streets. Those who had seen these excavations described gravels overlying the limestone bed rock and the descriptions fitted those of the pre-Illinoian drift very precisely. At the Southwestern Bell Telephone Building the drift was about two or three feet in thickness. At the Postoffice, the drift was thin at the northern end and thickened rapidly to the south to the unusual thickness of 18 feet. This is the general direction of the Mill Creek valley. The surface of the bed rock slopes in the same direction.

The pre-Illinoian drift in St. Louis is composed of a very stiff, dark reddish or brownish clay, sprinkled thickly with pebbles and cobbles, and with occasional boulders. It has been described as a blue clay by some, but the typical exposure of the reported blue clay has long since been covered. The thickness varies from two to a reported eighteen feet. Most of the exposures in the city of St. Louis seen by the writer hardly exceed eight feet in thickness.

The pebbles are predominately of chert, as shown by numerous pebble analyses (Table III). Quartzite is easily the next in abundance. Many of the quartzite pebbles and cobbles, and most of the quartzite boulders, have a reddish or purplish color, and many are banded in such a way as to closely resemble typical Baraboo quartzite. If the drift ever contained any limestone or dolomite pebbles, they have long since been completely removed by leaching. Not a calcareous pebble has been found by the writer in any pre-Illinoian drift in St. Louis.

FIGURE 21. Closer view of the pre-Illinoian drift at the same locality as shown in Figure 20.

FIGURE 20. General view of the pre-Illinoian drift at the east end of Forest Park, St. Louis, exposed in the winter of 1935-36 in a cut for the super-highway crossing the Park.

One of the most significant discoveries in the drift was the presence of blue hematite. It was first noticed among the pebbles in the collection which Drushell had made from the St. Louis drift and had presented to the Department of Geology and Geography at Washington University. The pebble is about an inch and a half in diameter and of a type of blue hematite closely resembling that from the Lake Superior district. When Prof. Drushell was in St Louis, he kindly identified the label of the box containing the hematite as written by himself and the contents as collected near the Shaw School.

In north St. Louis, in the area covered by Illinoian drift there appears in certain localities another drift usually underlying the Illinoian drift that has been described as pre-Illinoian by some writers. Pebble analyses seem to accord with this view. But as previously stated, it is possible that this apparently older drift is merely a mixture of lower Illinoian drift and Lafayette gravel. At present there seems to be no positive evidence either way.

The pre-Illinoian drift in St. Louis has been ascribed by some to the Kansan ice sheet, by others to the Nebraskan. Drushell[27] thought that both ice sheets might have been involved. The evidence at present available is not conclusive, although it doubtless favors the Kansan ice sheet as the source of at least some of the drift. The origin of much, if not all, of the drift seems to have been in the northwest, from the Kewatin center, as shown by the large number of purple quartzite boulders and the corroborating testimony of the blue hematite. It would appear entirely reasonable that a tongue from the ice sheet in Lincoln County, which certainly crossed the Missouri River, proceeded into St. Louis. Leighton[28] is inclined to correlate the drift on the bluffs at Alton with a tongue of ice moving in a northeasterly direction and there is evidence to support this and no direct evidence against it. On the other hand, it is possible that the St. Louis drift, or a part of it, represents the farthest southward advance of ice from the Kewatin center in Nebraskan times. More detailed evidence will be needed before the question can be finally settled.

PLEISTOCENE HISTORY OF THE MIDDLE MISSISSIPPI RIVER REGION

The terraces and drift which have been described, are the clues to the succession of events which occurred in the Middle Mississippi River Region during Pleistocene time. In interpreting these events it is necessary to recognize that the number of years involved in the Pleistocene period is small in comparison with the number involved in earlier geologic periods. On the contrary, the time is long in comparison with the time considered by the historian or even by the archaeologist.

Several estimates of the time involved in the successive stages of Pleistocene glaciation have been made by various geologists. Perhaps the following time scale by Kay[29] (Table VII) based on the depth of weathering sustained by the various drift sheets in Iowa, is as satisfactory as can be found. Daly[30] thinks the Aftonian interval may be too long. In describing the Pleistocene history of the area the nomenclature adopted by Kay and Leighton will be used (Table VIII).

Pre-Pleistocene Topography and Drainage

In the Middle Mississippi River Region the various ice sheets apparently moved over a terrain essentially like the one now seen. The master streams were incised in a broad plain. During the time the ice sheets were in the region, and for a short interval thereafter, the changes wrought by the ice sheets undoubtedly appeared great. These changes proved to be ephemeral. Only relatively inconspicuous fragments of the changes wrought by the ice are discernible today. The unindurated mantle rock, which forms a relatively thin veneer over the bedrock in most of the region, contains practically all of the evidence of all the changes produced by four successive invasions of mighty ice sheets, of which at least three covered or approached very closely to the Middle Mississippi River Region.

It has been thought by some, including Leverett,[31] that the Mississippi River north of the region under consideration oc-

Today	Inter-glacial Glacial
	Recent
Years ago	Wisconsin
	Peorian
	Iowan
100,000	
	Sangamon
	Illinoian
200,000	
300,000	Yarmouth
400,00	
	Kansan
500,000	
600,000	Aftonian
700,000	Nebraskan

TABLE VII.

Time scale of the Pleistocene modified from estima tes by George F. Kay.

TABLE VIII.

Classification of the Pleistocene Period according to Kay and Leighton.*

PERIOD (System)	EPOCH (Series)	AGE (Stage)	(Sub-stage)
PLEISTOCENE		Recent	
	Eldoran		
		Wisconsin	Mankato, glacial
			Carey, glacial
			Tazewell, glacial
			Iowan, glacial
	Centralian	Sangamon	inter-glacial
		Illinoian,	glacial
	Ottumwan	Yarmouth,	inter-glacial
		Kansan,	glacial
	Grandian	Afton,	inter-glacial
		Nebraskan,	glacial

Kay, George F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, p. 449, 1931.

Kay, Gorge F., and Leighton, Morris M., Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, p. 673, 1933.

cupied the present course of the Illinois River. Apparently the present trough of the Mississippi, above the Illinois, was used by a relatively unimportant tributary. This appears to be the only major difference in the drainage of the region that developed during the entire Pleistocene.

Grandian Epoch

During the Nebraskan age it seems reasonably certain that an ice sheet invaded Scott County in Illinois in the vicinity of Winchester (Fig. 18.) This is perhaps the only completely demonstrated fact regarding Nebraskan glaciation in this vicinity and, at that, Winchester is many miles north of the Middle Mississippi River Region. There are many important questions regarding the results of the Nebraskan ice sheet. Is the drift in the quarries above Alton of Nebraskan age? Is any or all of the pre-Illinoian drift in St. Louis of Nebraskan age? Did the Nebraskan ice border actually extend beyond the better known and much later Illinoian ice border? These questions have been raised by geologists at one time or another. The answer for the present must be that there is no positive evidence upon which any of them can be answered, and the final answer to these questions must rest upon more detailed knowledge.

Ottumwan Epoch

An ice lobe from the Kewatin center entered Lincoln County from the north (Fig. 14). It spread eastward across the present course of the Mississippi River into Calhoun County near Batchtown, Illinois. This must have dammed the stream, if there was one, that flowed in the course which the Mississippi now occupies north of this point. A part of the ice sheet extended southward across St. Charles County and reached the south bank of the Missouri River in the general vicinity of Vigus, St. Louis County. The Missouri River was thereby dammed above this point. The ice front of this Kansan lobe was probably parallel to the present course of the Missouri River to the westward, but some distance north of it. There were some pools of quiet water adjacent to the ice front in which a considerable

thickness of fine glacial flour was deposited as a blue clay. In at least one spot near Elm Point a mastodon was mired in the blue clay.

The Missouri River, being dammed and still receiving large quantities of sediment from its headwaters, rapidly accumulated sediment in thick layers. Thus was produced the Boeuf Terrace. This accumulation may very probably have occurred rapidly and it is not necessary to believe that the river was blockaded for any great length of time. As these sediments were being accumulated, the ice front probably formed at least part of the northern, as well as the northeastern, shore of the lake. From this ice front icebergs escaped, and floating over the surface of the lake and melting, deposited whatever cobbles, boulders, and other detritus they contained, in the midst of the accumulating silt in the bottom of the lake.

It seems probable, but not certain, that the pre-Illinoian drift in St. Louis is of Kansan age. The drift is probably from the Kewatin center. If this is true, it would seem probable that some of the ice from Lincoln County which crossed the Missouri River continued southeastward, depositing the drift now found in the City of St. Louis.

Leighton[32] has suspected that the drift at Alton was of Kansan age and that it came from the southwest, that in some way an extension of the Lincoln County ice sheet swung in this direction. He thought that this would account for cerain striations of the limestone at Alton, recorded by Leverett.[33] If Leighton is correct, then it would seem that the Mississippi River, at that time occupying the present course of the Illinois River, must have been dammed above Alton, and that a terrace corresponding in some respects to the Boeuf Terrace should be traceable in the Illinois River as it is in the Missouri River. The investigation has not yet been carried far enough to check this point.

With the retreat of the Kansan ice in Yarmouth time, the Missouri River started eroding the Boeuf Terrace, and now

only fragments of it are preserved in the tributaries of the Missouri River.

Centralian Epoch

The Illinoian ice sheet originated in the Labrador peninsula. In the Middle Mississippi River Region the border of the ice was essentially parallel to the river itself as far south as Murphysboro. Apparently a terminal moraine was built up by the ice in some places.

So far as the drainage of the Middle Mississippi River is concerned, the most important event of the Illinoian age was the crossing of the river by a tongue of ice from the main ice lobe. This tongue probably extended westward between Edwardsville in Madison County, and Caseyville in St. Clair County, Illinois. As it moved slowly westward, the course of the Mississippi River was deflected westward around the ice front. The river impinged upon the relatively unresistant Pennsylvanian clastic sediments and eroded a scallop in the west bank of the stream. Eventually the ice front reached the western side of the trough of the river. The northern edge of the tongue of ice rested against the cliffs at a point about two miles north of the pumping station of the water works at Chain-of-Rocks, St. Louis. The southern edge of the ice rested upon the present site of O'Fallon Park. It is probable that there was a slight reentrant in the tongue of ice and that some of the water-lain sediments in the vicinity of Chain-of-Rocks may have been deposited in this reëntrant.

This extension of the ice seems to have formed, at least eventually, an effective barrier to the Mississippi above Chain-of-Rocks. In the lake thus formed extensive alluvial deposits were made. They are so extensive that it would seem quite probable that the tongue of ice built a moraine which formed a competent barrier for the waters even after the ice had retreated from the region. The upper surface of the lake must have had

an elevation of about 530 feet. The elevation of the upper surface of the deposit is usually between 510 and 530 feet. This is the Cuivre Terrace. The lake in which the deposit was formed came in contact with the front of the ice sheet for only a short distance, from the point in St. Louis County north of the St. Louis Pumping Station before referred to, for a distance of perhaps 20 miles to the east and the northeast. The only place where ice-rafted boulders were found in the Cuivre Terrace was in the vicinity of this ice front near the Oak Grove School, Madison County, Illinois.

The spillway for this lake while the ice was still present may have been over rather low ground west of O'Fallon Park. After the retreat of the ice, it would seem probable that the spillway was over the moraine. The stratification which can be seen in the upper ten feet of the till at Edwardsville certainly suggests reworking by water. The elevation of the base of this reworked till is 480 feet. The problem of spillways for the rivers north of the ice dam presents several interesting points for further study.

In post-Illinoian, or Sangamon, time the morainal dam was subjected to erosion. It probably did not take very long for a channel to be eroded capable of removing the water from the lake; but the complete erosion of the moraine undoubtedly took much longer. In fact, it is possible that the drift has not been entirely removed up to the present time. It may be that the bases of the so-called Indian mounds in the flood plain of the Mississippi River near Caseyville are remnants of this moraine formed in Illinoian time, though the writer is inclined to doubt it.

During the retreat of the Illinoian ice sheet, streams in Illinois whose headwaters were receiving the sediment-laden water from the melting ice were aggrading and built up flood plains, which later erosion left in the form of terraces whose longitudinal surfaces sloped essentially parallel to the profile of the streams.

Such terraces may be traced along the Kaskaskia River and in some other tributaries of the Middle Mississippi on the Illinois side of the river, south of St. Louis.

Eldoran Epoch

It is held by geologists that a stream flowing from a melting glacier is ordinarily an aggrading stream. The Middle Mississippi trough was apparently aggraded to an elevation of about 50 feet above the present floodplain during the retreat of the Wisconsin ice. This aggradation produced the Festus Terrace. While the main stream was thus being aggraded, tributaries on both sides of the river were dammed, producing lakes in their lower courses. At times of flood the sediment-ladened waters of the Mississippi carried deposits into the mouths of the tributary streams, thereby producing delta-like deposits.

As the Wisconsin ice sheet retreated, there came a time when the waters from the retreating ice passed through several stages of the Glacial Great Lakes. These lakes provided settling basins for the great volumes of water from the melting ice. The Mississippi River, having deposited most of its load, again became capable of erosion. It was, in a sense, a rejuvenated stream. As the main trough was cleared of sediments, most of the tributary streams cut through the delta-like deposits at their mouths. The vast volumes of the Mississippi River caused it to remove the sediment it had deposited more rapidly and more completely than was the case in most of the tributaries. This is more specifically true for the Middle Mississippi River Region than above it. Remnants of the old floodplain deposits are still to be found as terraces bordering the Illinois River in Calhoun County.

Similar terraces may be traced in both the Missouri and Mississippi rivers. But below this triple confluence, no terrace that can be definitely identified as due to aggradation during Wisconsin time may be pointed out in the trough of the river.

But it is reasonable to assume that a considerable portion of the sediment found on the flood plain of the Mississippi River today was deposited in Wisconsin time.

The tributaries to the Middle Mississippi, however, were not as efficient eroding agents as the master stream; and fragments of the deposits made during Wisconsin time, in other words, fragments of the Festus Terrace, may be traced along the banks of these tributaries, usually for several miles from their mouths.

In a few instances the tributary stream was unable to cut through the deposit which choked its mouth. Sandy Creek in Jefferson County, Missouri, formed a water-gap into Joachim Creek to the south, abandoning its former outlet at Riverside (Fig. 6). As a matter of fact, the drainage has been diverted from nearly two miles of its lower course.

At the mouth of Hubbel Creek, in Cape Girardeau County, the Mississippi was silted up to the level of the tops of the confining bluffs. Under this condition, the mouth of Hubbel Creek was deflected downstream, as is quite common in the case of tributaries. Hubbel Creek was a superimposed stream. When the master stream began to remove its accumulated sediment, Hubbel Creek remained in its new channel and eroded the sandstone underlying the new course, instead of the unconsolidated sediments of its old course. This has produced a youthful canyon at the mouth of the river, quite out of harmony with the mature course farther upstream.

There is an abrupt change in the elevation of the Festus Terrace in the vicinity of Wittenberg, Perry County, Missouri. The fragment of the terrace south of this point are consistently about 40 feet lower than are the fragments to the north of this point. This raises the question as to whether there may not have been diastrophic movement in late or post-Wisconsin time to acount of this discrepancy in summit levels. A fault, which

runs from Red Rock in Perry County, through Wittenberg, disappears below the Mississippi at about this place and this seems to be very close to the boundary between the two groups of terrace levels. Although the evidence is by no means conclusive it is certainly an indication of post-Wisconsin movement, either along this fault or another one that might be concealed near it. It may be worth while to mention that Shepherd[11] wrote in connection with he New Madrid earthquake:

> ". . . the primal cause of the New Madrid earthquake may have been due to readjustments of fault lines in the Ozarks."

By this it is not intimated that the New Madrid earthquake was occasioned by movement along the fault between Red Rock and Wittenberg. Rather it is intended to point out that there are reasons to believe that there have been recent movements on some of the faults in the Ozarks and that the displacement of the Festus Terrace by movement along a fault in post-Wisconsin time is an entirely reasonable assumption.

Pleistocene History Summary

1. Grandian epoch: the Nebraskan ice reached a point about 25 miles north of the confluence of the Illinois, Mississippi and Missouri Rivers. Further ideas regarding the Nebraskan in this region are at present conjectural.

2. Ottumwan epoch: the Kansan ice from the Keewatin center made extensive deposits of drift in Lincoln County, Missouri. This ice sheet blocked the stream that at that time occupied the present valley of the Mississippi. It also blocked the Missouri River in the general vicinity of Vigus in St. Louis County, thereby producing the Boeuf Terrace up the Missouri River. The ice probably extended into St. Louis and even turned northeastward to Alton. If this was so, the Mississippi River, at that time occupying the present course of the Illinois River, must also have been blockaded. Kansan ice, from the Labrador

center, approached the Middle Mississippi River Region from the east, but apparently did not cross the river.

3. Centralian epoch: the principal Illinoian ice front was parallel to the Mississippi River in this region. A tongue of ice extended across the Mississippi River from about Edwardsville to the St. Louis side of the river. Thick deposits of drift were formed in O'Fallon Park, St. Louis. This ice tongue, and probably its corresponding moraine, dammed the Mississippi River, producing a very extensive lake in which the Cuivre Terrace was deposited.

4. Eldoran epoch: The Wisconsin valley-train produced the Festus Terrace, which has been considerably eroded in subsequent time.

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VOLUME XXX

May, 1939

to

June, 1941

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ELMER D. BUEKER

Senior High School, University City, Mo.

Issued May 1, 1939

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Springtails (Collembola) of the St. Louis Area

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Senior High School, University City, Mo.

Issued May 1, 1939

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Springtails (Collembola) of the St. Louis Area

ELMER D. BUEKER

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The insects may be grouped into the primitive wingless group, subclass *Apterygota,* and the winged, subclass *Pterygota.* The springtails, *Collembola,* and the bristle-tails, *Thysanura,* are the two orders of the subclass, *Apterygota.* The wingless condition of this subclass is a primitive one and has not been acquired as a result of parasitic habit as in lice and fleas. Chewing mouth parts, wingless condition, and young which resemble adults in form indicate a likely resemblance to the earliest forms of insect life. Florissant Colorado deposits have yielded a species, *Planocephalus aselloides* Scudder, 1890, which is related to present day *Collembola* and yet shows some affinities to *Thysanura.* Species of *Collembola* developed a springing organ, the furcula, which is attached to the ventral side of the fourth abdominal segment. This appendage is normally folded beneath the abdomen. When the insect suddenly extends this organ it springs about; hence, the name springtails.

Living usually in darkness has probably been a factor in the development of vestigal compound eyes or the loss of eyes. In some species seven or eight ommatidia are present on each side of the head. In others there are less than the above number or eyes may be absent.

On the ventral side of the first abdominal segment is a ventral tube which varies greatly in length in the different species. Sticky fluid on the end of this tube enables the insect to crawl on the under side of smooth surfaces.

Tracheae are generally lacking so that oxygen is apparently taken through the moist body surfaces. However, species of the genus *Sminthurus* have tracheae in a vertical fold on each side of the neck.

According to Folsom (1934) some two thousand species of this order have been named. Seventy-nine species have been listed from New York, one hundred thirty-two from Iowa, and fifty-eight from Minnesota. There is no list of the Missouri species that is at all comprehensive.

The characteristic position of the collector in gathering is on hands and knees examining humus and damp soil. Specimens are found in most any habitat where the relative humidity is sufficiently high. They are general feeders, but the range of relative humidity in which existence is possible is narrow. Davis and Harris (1936) found that *Pseudosinella violenta* (Folsom) survives best at relative humidities between 90-100 per cent, the optimum being about 100 percent. They will withstand the most extreme cold and are very active while most insect life is hibernating.

It is hard to understand why so many species are cosmopolitan. Of the one hundred thirty-two species from Iowa, fifty-nine are cosmopolitan in their range (Mills, 1934). This wide

distribution cannot be accounted for as due to the means of locomotion. It seems possible that running water has been the greatest means of distribution. *Podura aquatica* L., *Isotomurus palustris* (Müller), *Isotoma viridis* Bourlet and others are frequently taken from the surface of water. Mountain ranges and elevated areas such as the Ozark region, should therefore serve as centers from which species are distributed.

An instrument of value in collecting is described by Mills (1934); a piece of rubber tubing with a glass mouthpiece at one end and inserted at the other end a glass tube drawn out to a small aperture distally and closed by bolting cloth at the base. By sucking air in quickly insects may be removed from cracks and from humus and shaken into preserving fluid. Folsom (1915) states that a camel's hair brush is a handy collecting device. One should be provided with paper labels and a large number of small vials filled with 90% alcohol. Insects are dropped into the alcohol and then may be removed from the vials and placed into beechwood creosote and allowed to clear. They may remain in the beechwood creosote until it is convenient to mount them permanently in Canada balsam. The specimens must be kept in the creosote at least three hours. Potassium hydroxide may be used to clear extremely dark specimens.

When live specimens are placed into an empty vial they jump about until they are completely exhausted and death soon follows. With moist soil in the container they will live for two or three days. If the soil is not too deep the animals will often make their way to the bottom of the container where light is present. Instinctively they crawl under objects and the presence tropic. Instinctively they crawl under objects and the presence of light does not seem to be offensive. If the overlying object be removed, the furcula springing reflex is set up and will continue until the insect again finds itself beneath something. Harris and Davis (1936) state that positive thigmotropism is a strong factor in producing these responses.

Folsom (1933), in discussing the economic importance of *Collembola,* states that there are forty species that are important. He says, "The greatest damage by springtails is done to young, tender plants, especially seedlings. The springtails make holes in leaves gradually piercing leaves completely and characteristically leaving the epidermis at the end of the puncture intact. They feed also on wounds made by flea beetles, potato beetles, and other insects. Many species injure the stems of plants just below the surface of the ground and cut through them. On the roots springtails cause injury by gnawing pits and by destroying root hairs and small rootlets."

The genital apertures of both sexes are ventral to the fifth abdominal segment and the anal opening is ventral to the sixth. There is an enlarged somewhat flattened papilla on the male on the end of which is a round genital opening. In the female the homologous opening is transverse with a posterior and an anterior lip. Since this characteristic of the sexes is difficult to distinguish and since the sexes are otherwise alike no mention is made in descriptions as the sex.

There are six or seven nymphal instars before the imago appears (Davis and Harris 1936; Maclagan 1932). The nymphal stages resemble the adult so much externally that little or no mention is made in descriptions of species as to which stage is used.

ORDER *(Collembola)* Lubbock, 1870

The species belonging to this order are without a noticeable metamorphosis. At no stage are wings present. The abdomen has three appendages; the ventral tube on the ventral side of the first abdominal segment, a tenaculum on the ventral side of the third segment, and the springing organ, the furcula, at the end of the fourth or fifth. The proximal part of the furcula is known as the manubrium, the distal half as the dentes and the tip of the dentes as the mucro. The legs are composed of

the following segments beginning at the proximal end: two pre-coxa, coxa, trochanter, femur, tibio-tarsus. At the end of the tibio-tarsus there is either one claw, the unguis, or an unguis and a smaller claw, the unguiculus. This order is subdivided into two suborders:

Body elongate with the segments distinct, last two or three abdominal segments are often more or less fused in some species. Suborder *Arthropleona* Börner.

Body subglobose with thoracic and abdominal segments fused except for the last two segments of the abdomen. Suborder *Symphypleona* Börner.

Families of the Suborder *Arthropleona* Börner, 1901:

Prothorax naked dorsally and usually covered by a forward projecting mesonotum, furcula usually present; absent only in the genus *Anurophurus*. *Entomobryidae* Tömösvary.

Prothorax with dorsal bristles and not covered dorsally with forward projecting mesonotum. *Poduridae* Lubbock.

Subfamilies of the Family *Entomobryidae* Tömösvary, 1883:

Tergum of the fourth abdominal segment much longer than the third. Subfamily *Entomobryinae* Schäffer.

Tergum of the third and fourth segments subequal, body scaled, third and fourth segments of antennae subsegmented. Subfamily *Tomocerinae* Schäffer.

Body not scaled, third and fourth segments of abdomen subequal, third and fourth segments of antennae rarely annulate. Subfamily *Isotominae* Schäffer.

Famlies of the Suborder *Symphypleona* Börner, 1901:

Antennae much shorter than the head, very small insects. Family *Neelidae* Folsom.

Antennae longer than the head, body size variable. Family *Sminthuridae* Lubbock.

FAMILY *Poduridae* LUBBOCK, 1870

Pronotum well developed and furnished with dorsal setae; antennae thick and heavy and usually not much longer than the head; anal horns sometimes present; furcula present or absent.

Podura aquatica L., 1758

Figures 1-2. Length .5-1.8 mm; short thick body; dark brown to black; two darker eyespots; antennae 3-segmented, segments to each other as 1, 1. 4, 2; feet with only the unguis; dentes slightly bowed outward and with the distal half annulate.

Specimens are often found attached to weed stems slightly above the surface of the water along the margins of lakes and ponds. Others are on the surface of the water. Shaking the weeds causes them to jump to the surface of the water where they seemingly jump about at random until they by chance come near an upright weed stem where they attach themselves. Some live animals were kept in upright glass tubes and it was found that they will crawl or jump toward a source of light. They do not apparently prefer a dark background as one would expect becaause of their dark black or brown bodies. This species occurs in large numbers and is of importance as food for small fish. It is cosmopolitan. Records: December 26, 1936, one mile south of Warrensburg, Mo., (E. D. Bueker); May 1, 1938, puddle in the road, 4.5 miles northwest of Ashland, Boone Co., Mo. (Leslie Hubricht); January, 1939, Lagoon in Forest Park, St. Louis, Mo., (E. D. Bueker).

Achorutes armatus Nicolet, 1841

Figure 7; length 1-1.5 mm; black; furcula small; antennae 4-segmented, subequal to the length of the head, segments to each other as 1, 1.2, 1.2, 1.4; short setae covering the body, and a few longer setae near the middle part of each segment dorsally; unguiculus absent; one long knobbed hair above the unguis on the distal end of the tibio-tarsus. Records: March 4, 1934 Ranken, Mo., (E. P. Meiners).

Onychiurus subtenuis Folsom, 1917

Figures 3-6; length up to 1.8 mm.; white; body covered with minute tubercles and a few long setae; distinct body segments; segments subequal; no furcula; two anal spines which appear quite long because they are located on prominent tubercles; unguis about as long as the anal spine and with one or two teeth on the inner surface; no tenent hair; unguiculus spine-like, with a basal lamella; antennae 4-segmented, segments to each other as 1, 1.4, 1.6, 2, third segment with a distinct notch near the distal end.

The notch on the third antennal segment and the prominent anal horns which are as long or slightly longer than the hind unguis are characteristics useful in identifying this species. This is a common species in the St. Louis area, and is found in leaf mold and rich humus. Reported by Mills (1934) as found also in Illinois, New York, Pennsylvania, Utah, Ontario. Records: March 15, 1936, Buder Park, one mile southeast of Valley Park, Mo., (Leslie Hubricht); November 7, 1937, Ranken, Mo., (E. D. Bueker).

Subfamily *Entomobryinae* Schäffer, 1896

The fourth abdominal segment usually much longer than the third dorsally, if subequal then the antennae are five or six seg-

mented or the fourth antennal segment is as long as the whole body; otherwise the antennae are four segmented and the fourth segment is much shorter than the body. Unguiculus and furcula always present.

GENUS *Entomobrya* Rondani, 1861

Pigment well developed and often present in a definite pattern; tenent hair well developed; mucro with an apical and a subapical tooth and a basal spine; without scales; eyes eight on each side.

Entomobrya purpurascens (Packard), 1873

Figures 48-52; length 1.5 mm.; white or yellow with black markings; tenent hair numerous on the dorsal surface of the head, mesothorax and metathorax, but less numerous over the rest of the dorsal body surfaces; prothorax without markings; mesothorax with darkened areas laterally near the base of each leg; metathorax with posterior parts and lower lateral parts heavily chitinized and darkened; posterior half of first abdominal segment with an irregular transverse band; second abdominal segment entirely darkened except for a narrow strip on the anterior dorsal part; third segment entirely darkened but for a small anterior dorsal part; fourth segment with a broad irregular darkened transverse band over the entire surface except for an irregular anterior dorsal region; fifth and sixth segments also darkened; entire body covered with many short setae, furcula extending to the ventral tube, dentes dorsally crenulate, mucro with an apical and a subapical tooth; ommatidia nearest the bases of the antennae on each side with 16-19 small round black bodies; unguis with 3 inner, 2 lateral and one outer teeth; unguiculus slender and two-thirds the length of the unguis; antennae about twice the length of the head, segments to each other as 1, 1.9, 1.8, 2.2.

According to Mills (1934) this species is found in Illinois, Louisiana, Massachusetts, Maine, Minnessota, North Dakota, New Hampshire, New York, Tennessee, Texas, Wisconsin, Canada. Records: March 4, 1934, Ranken, Mo., (E. P. Meiners).

Entomobrya multifasciata (Tullberg) 1871

Figures 57-58; length approximately 1.5-2 mm.; light yellow with black or dark blue markings; each segment except the prothorax with a dark band on the posterior margin dorsally and laterally; many tenent hair present on the dorsal side of the head, mesothorax and metathorax, very sparse on the abdomen and in some specimens mostly lacking in this region; entire body covered with small setae; antennae 1.5-2 times the length of the head, segments to each other as 1, 2, 1.8, 2; a dark strip between the antennae containing a black triangular area; furcula extending to the ventral tube, mucro with an apical and a subapical tooth.

This species is more common in the southern states. It is, however, cosmopolitan and usually taken from humus. Records: March 4, 1934, Ranken, Missouri, (E. P. Meiners).

Entomobrya assuata Folsom, 1924

Figures 32-35; length 1.5-2 mm.; black with light yellow markings; a black line extending between the eyespots, and V-shaped marks on the dorsal side of the head back of the eyespots; prothorax covered dorsally by forward projecting mesonotum; mesothorax mostly colorless dorsally and the metathorax entirely darkened except for an area near the median line; first segment of abdomen irregularly darkened dorsally, second segment with a dark band near the posterior edge of the segment and a widened dark area near the median line, third entirely covered with dark chitin, fourth three or four times longer than the third with the posterior half covered with a dark area, fifth and sixth with dark chitin; mucro strongly rounded ventrally

with an apical and subapical tooth and a proximal spine; unguis with three teeth on the inner surface, unguiculus about two-thirds the unguis; antennae four segmented, antennae about twice the length of the head, segments to each other as 1, 2, 1.8; 2.2; numerous strongly knobbed tenent hair present.

Large numbers were found in empty elongated galls of twigs of black locust. Records: March 12, 1938, Vinita Terrace, St. Louis, County, Missouri. (E. D. Bueker).

Entomobrya duolineata N. Sp.

Figures 59-61; length 2.5-3 mm.; yellow with black markings; antennae four segmented, segments to each other as 1.0, 1.6, 1.6, 2.2, first two antennal segments with tenent hair; prothorax covered dorsally by forward projecting mesothorax; dorsal surface of body segments with numerous tenent hair; entire body surface covered with numerous small setae; head with dark chitinized area laterally below eyespots, darkened area on lateral side of mesothorax near ventral side which extends to and including the second abdominal segment; dorsal side of metathorax with a dark area near the median line; a dark band covers most of entire surface of the third abdominal segment; fourth abdominal segment twice as long as the first three segments combined and with a dark band extending across the middle and another band at the posterior end; fifth segment entirely darkened; unguis well developed and strongly curved, unguiculus about as long as the unguis; mucro bidentate and with a well-developed spine; dentes crenulate dorsally.

This form was found to be very abundant in leaf mould during January with the temperature at about 45° F. Records: January 20, 21, 22, 1938, near the Washington School, Vinita Terrace, St. Louis County, Missouri, E. D. Bueker.

Entomobrya quadrilineata N. Sp.

Figures 44-47; length 2-2.5 mm.; light yellow with four black or bluish irregular longitudinal stripes, two on each side extending from the anterior margin of the mesothorax to the posterior margin of the second abdominal segment; segments three, four and five each with an irregular transverse stripe on the posterior third of the segment and an additional stripe across the middle of the fourth; dorsal side of fourth segment about four to five times the third; long tenent hair present on the dorsal anterior half of the body, much less abundant elsewhere; antennae 2 to 3 times the length of the head, segments to each other as 1, 1.6, 1.6, 2; dark band extending from one eyespot and antennal base to the other eyespot and antennal base; furcula extending to the ventral tube, dentes dorsally crenulate and covered with many small setae, mucro with apical and subapical tooth; some specimens with a clear area in one corner of each eyespot at the anterior edge nearest the antennae, this clear area containing from fifteen to twenty-six round black spots.

This species greatly resembles E. multifasciata but differs greatly in the markings. The four black irregular stripes, two on each side on the anterior part of the body as described, are not found on E. multifasciata. Instead, E multifasciata has transverse bands on these anterior segments. This species is commonly found in humus and protected top soil. Records: March 25, 1934, Ranken, Missouri, (E. P. Meiners); August 8, 1937, Chautauqua, Illinois, (E. D. Bueker).

GENUS *Orchesella* Templeton, 1835

Eyes, eight on each side. Antennae are six segmented, first two segments often obscure. The fourth abdominal segment never more than twice the third.

Orchesella hexfasciata (Harvey), 1895

Figures 53-56; length 1.8-2 mm.; yellow with dark purple markings; mesonotum with a dark purple transverse band anteriorly and laterally; metanotum with a dark transverse area anteriorly and widened laterally in two places to unite with two stripes across each side of the body; a black transverse stripe extending across the head near the antennae; and an irregular dark area present on each side of the head; antennae about three times the length of the head, segments to each other as 3, 14, 5, 17, 20, 26; a dark area near the middle of the first antennal segment, apical third of the second segment pigmented, third segment without pigment and obscurely separated from the fourth, distal half of the fourth dark; fifth and sixth obscurely annulated and entirely pigmented except for a small proximal part of each segment; dorsal side of fourth abdominal segment about twice the length of the third; ventral tube about two-thirds the length of the dentes; mucro with apical and subapical teeth and a proximal seta; tenent hair present; body covered with short curved setae.

This species is frequently found in the woods underneath leaves and in humus. This species has been recorded in Illinois, Louisiana, Massachusetts, Maine, New Hampshire, New York, Virginia, Wisconsin, Ontario. Records: July 25, 1937, Ranken, Missouri, (E. D. Bueker).

Orchesella ainsliei Folsom, 1924

Figures 62-65; length 1.3-2 mm.; yellow or brownish yellow with dark blue markings; body with two irregular lateral stripes on each side extending from the prothorax to the second abdominal segment, one lateral stripe extending weakly to the eyespots, mostly black dorsally and laterally from the second abdominal segment posteriorly but interrupted by narrow yellow bands; legs mostly light yellow except for irregular dark areas on the precoxal and coxal segments; antennae about three times

the length of the head, last two segments obscurely annulate, third segment about one-half the second and with a dark apical ring, first segment about one-fourth the second; furcula extending to the ventral tube; ventral tube about as long as the dentes; mucro with apical and subapical teeth and a proximal spine; tenent hair present; many short curving setae covering the body.

This species is commonly found under logs or dead leaves or in humus in the woods. This species may easily be identified by means of the markings over the body and the dark apical ring of the third antennal segment. This species also occurs in Europe and is common in the United States, and Canada. It is cosmopolitan. Records: March 25, 1934, Ranken, Missouri. (E. P. Meiners).

GENUS *Pseudosinella* Schäffer, 1897

Eyes absent or reduced. Pigment usually lacking. Mucro as in *Entomobrya*. Tenent hair weakly developed. Body scaled.

Pseudosinella violenta (Folsom), 1924

Figures 14-17; length 1.5-2 mm.; entire body white; no eyespots and no eyes; covered with some scales that are rounded; body segments visible but not distinct; antennae 4-segmented. segments to each other as 1, 1.8, 1.6, 2.8; dorsal side of fourth abdominal segment three times the length of the dorsal side of the third; furcula reaching to the ventral tube; tenent hair somewhat capitate; dentes dorsally crenulate and with setae, ventrally with scales; mucro slender, with one apical and one subapical tooth, both teeth directed dorsally.

This species is frequently found in manure during the summer months and seems to tolerate more temperature ranges than most species of *Collembola*. Dr. Harlow B. Mills states that

he has reared this species by putting specimens in a jar on damp soil and dropping an occasional peanut into the jar for food. This species may at times be of economic importance since it is injurious to roots of beets and sugar-cane. It may be easily identified by its white body, lack of eyes and eyespots, scales over the body and on the ventral side of the furcula. Folsom (1933) states that this species causes serious injury to roots of sugar cane; cosmopolitan in distribution. Records: August 8, 1937, Chautauqua, Illinois; July 25, 1937, Ranken, Missouri; November 7, 1937, Ranken, Missouri; (E. D. Bueker).

Subfamily *Tomocerinae* Schäffer, 1896

The fourth abdominal segment about the same length or somewhat shorter than the third. Antennae four segmented with the last two segments annulate, and the third segment much longer than the fourth. Unguiculus and furcula present. Mucro long and slender with apical and dorsal teeth, covered with hairs. Dental spines present and body scaled.

GENUS *Tomocerus* Nicolet, 1841

Tenent hair well developed. Eyes six on each side. Dental spines are well developed.

Tomocerus flavescens Tullberg, 1871

Figures 39-43; length 3-6 mm., most specimens between 3-4; body white or yellow to dark gray, mostly white or yellow during summer; large tenent hair present especially on the anterior edge of the mesonotum where it touches the head; scales covering the entire body of some specimens others are remarkably free of scales; mandibles with 3-4 tooth-like projections; labrum and labium about equal in size, labium with many long setae; antennae 2-3 mm. in length or one-half to two-thirds the length of the body, second about twice the length of the first,

last two segments annulate and covered with many small setae, third segment about 15 times longer than the fourth, first two segments often heavily chitinized, last two segments less chitinized; post antennal organ somewhat triangular; eyes not very conspicuous due to the scales and the heavily chitinized surfaces, but apparently six are present; abdominal segments distinctly separated, fourth segment shorter than the third; unguis with 3 teeth, unguiculus lanceolate, one club-shaped tenent hair present on the posterior basal part of each foot; furcula reaching to or almost to the ventral tube; dentes without crenate edge and with many short setae; out of 16 specimens examined 10 had two large proximal spines, 5 shorter intermediate spines, and two large distal spines on each of the two dentes of the furcula and, therefore, would be of the variety, *americanus* Schött; 3 specimens have only one large proximal spine on each dentes, then 5 intermediate spines, and then the two large distal spines and are probably of the variety *separatus* Folsom; three were without a large proximal spine; mucro with two or in some one large proximal teeth, 6-7 intermediate teeth, usually 7, and 2 large distal teeth.

This species is common in America and Europe and may be classified as cosmopolitan in distribution. Records: November 7, 1937, Ranken, Missouri, (E. D. Bueker); Buder Park near Valley Park, Missouri, March 15, 1936, (Leslie Hubricht); Ranken, Missouri, May 17, 1936; Vinita Terrace, Missouri, November 28, 1936; Grimsby, Missouri, November 22, 1936, (Leslie Hubricht); Ranken, Missouri, March 4, 1934, (E. P. Meiners); Ranken, Missouri, October 1936, (E. D. Bueker). This species is probably the most common and most conspicuous of *Collembola* in the St. Louis County region and can be taken most anywhere and during the entire year under leaf mold.

Subfamily *Isotominae* Schäffer, 1896

Antennae four segmented and about equal to the length of the head. The third and fourth abdominal segments are subequal. Body never with scales.

GENUS *Folsomia* Willem, 1902

Eyes usually reduced in number or absent. Body pigment lacking or reduced. Mucro usually with two teeth and only rarely three teeth. Abdominal segments four to six are often ankylosed completely. Sometimes the suture on the dorsal side between the fourth and fifth is evident.

Folsomia fimetaria (Linnaeus), 1758

Figures 18-21; approximately 1-2 mm.; white and completely without markings; eyespots entirely absent; antennae 4-segmented, segments to each other as 4, 8, 9, 15; unguis without teeth and somewhat curved, unguiculus about two-thirds as long as the unguis, lanceolate and untoothed; hind claws larger than other claws without tenent hair; abdominal segments 4, 5, and 6 without dorsal sutures; 20-25 crenulations dorsal of the dentes; mucrones bidentate; a few scattered long setae over the body surface and more numerous small setae.

Records: March 15, 1936, Buder Park, one mile west of Valley Park, Missouri, (Leslie Hubricht).

GENUS *Isotomurus* Börner, 1903

Eyes eight on each side. Unguiculus and furcula present. Dorsal side of the dentes crenulate; dentes long and slender. Mucro lamellate, four-toothed.

Isotomurus palustris (Müller), 1776

Figures 22-28; length approximately 1.5-2 mm.; under parts and legs lighter than the upper parts; with a dark irregular dorsal median stripe and a somewhat lighter irregular stripe on each side of the body; furcula with some pigment on the proximal part and attached to the fifth segment; antennae 4-segmented and somewhat longer than the head, segments to each

other as 1, 1.6, 1.8, 2.2; mucro four-toothed, dentes crenulate dorsally; tenent hair absent, sparsely covered with small setae; unguis with 2 lateral teeth, inner margin untoothed; unguiculus approximately one-half to two-thirds the length of the unguis; eyes eight on each side.

This species and *Podura aquatica L.* were found in great abundance on the margins of lakes and ponds. The median dorsal black stripe which varies somewhat in the individuals examined serves best as a single characteristic by which this form may be identified. Dr. Folsom states that this species is common and cosmopolitan in distribution and very important as food for trout an inch or less in length. Records: December 24, 1936; one mile southwest of Warrensburg, Missouri; (E. D. Bueker).

GENUS *Isotoma* Bourlet, 1839

Manubrium much shorter than the dentes. Unguiculus and furcula present. The third and fourth abdominal segments about equal. Eyes variable. Corpus of tenaculum usually with many anterior setae.

Isotoma viridis Bourlet, 1839

Figures 36-38; length 2-4 mm.; most specimens preserved in alcohol are a yellow green or a dark green; the body segments banded posteriorly with darker chitin; antennae four-segmented, one and one-half to two times the length of the head, second and third segments subequal and 1.8 times the length of the first segment, fourth segment twice the first; all segments of the body very distinct, third segment slightly longer than the fourth and extending ventrally beneath the fourth; furcula attached to the fifth segment and extending to the ventral tube; tenaculum quadridentate; unguis with two lateral teeth and a very distinct tooth on the outer edge, two small inconspicuous teeth on the inner edge, inner teeth sometimes absent; unguiculus

about one-half the length of the unguis with a tooth near the middle of the inner margin; without tenent hair on any part of the body; mucro tridentate, last two teeth of mucro opposite each other; dentes crenulate dorsally and with many short setae; a few large setae on the proximal three segments of each leg; numerous small setae on the three distal leg segments; the larger setae on the abdominal and meta and meso thoracic segments are more or less distributed around the lighter round and facet-like spots; round and hexagonal facet-like spots are near the middle lateral region of each segment except the first thoracic and the last abdominal, approximately 6-8 spots lateral of each side of the head below the black rectangular eyespots, 12-15 on each side of the fourth abdominal segment; body gradually tapering from the first thoraic segment to the last abdominal.

This is a large conspicuous species and is cosmopolitan in distribution. According to Folsom (1937) there are several varieties of this species. Records: March 25, 1934, Ranken, Missouri, (E. P. Meiners). A large number of specimens were taken at this time from humus.

Isotoma cinerea Nicolet, 1847

Figures 8-13; length 1.5-2 mm.; grayish to dark green; antennae 4-segmented and slightly longer than the head; segments to each other as 1, 1.8, 2, 2.2; eyespots well-developed; no conspicuous markings; body covered with short setae and a few longer setae on the dorsal surfaces of the fourth, fifth, and sixth abdominal segments; unguis well-developed; unguiculus about two-thirds the length of the unguis; claws with at least two tenent hair; furcula not reaching to the ventral tube; mucro with one apical spine and two anteapical spines pointing ventrally.

Records: February 5, 1938, under bark of willow tree, Vinita Terrace, St. Louis County, Missouri, (E. D. Bueker).

FAMILY *Sminthuridae* Lubbock, 1870

Antennae longer than the head, inserted near the vertex; the antennae four-segmented, with the fourth segment subdivided into segments, sometimes the third is also subdivided. Thorax is small, with abdomen much rounded and having an anal papilla.

GENUS *Ptenothrix* Börner, 1906

Third and fourth antennal segments are subdivided. Dentes dorsally with large serrate setae.

Ptenothrix unicolor (Harvey), 1893

Figures 29-31; length 1.5-2 mm.; brown to dark brown; antennae almost as long as the body, third and fourth segments subsegmented, between the proximal segment of the third and the enlarged apical segment of the third are six subequal short segments, fourth segment with four short subequal segments and a longer apical conical segment; each eyespot with eight eyes; unguis with two inner teeth and two lateral teeth; unguiculus with a well-developed inner tooth and an apical seta which extends beyond the unguis; each dorsal margin of the unguis with approximately 19-24 serrate-like teeth.

This form is commonly found under logs, bark, and in humus. Records: November 22, 1936, Grimbsy, St. Louis County, Missouri, (Leslie Hubricht).

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Podura aquatica

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Isotoma cinerea

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Pseudosinella violenta

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Folsomia fimetaria

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23. Dorsal markings of specimen, X-15
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Entomobrya assuata

32. Dorsal view of specimen, X-35
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34. Elongated gall of black locust twig,
35. Mucro, X-140

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PLATE I

EXPLANATION OF PLATES

Plate II

Isotoma viridis

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Tomocerus flavescens

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PLATE II

EXPLANATION OF PLATES

Plate III

Entomobrya quadrilineata n. sp.

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Orchesella hexfasciata

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Entomobrya multifasciata

57. Dorsal side of thorax and abdomen, X-60
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Entomobrya duolineata n. sp.

59. Specimen, X-25
60. Hind claw, X-140
61. Mucro, X-140

Orchesella ainsliei

62. Thorax and abdomen, X-50
63. Head, X-50
64. Hind claw, X-140
65. Mucro, X-140

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ARTHUR B. COZZENS

University of Illinois

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Analyzing and Mapping Natural Landscape Factors of the Ozark Province

ARTHUR B. COZZENS

University of Illinois

A recent paper on the cartographic representation of surface features[1] calls to mind the inadequacy of the maps available for the Ozark Province. Published maps show the distribution of various factors of the natural environment, but all of the maps lack detail and few even approach a quantitative basis. Furthermore, most of them present only one environmental element and do not emphasize the relationshlips existing among the elements. Briefly, the Ozark Province has not been "unduly contaminated by analytic investigation".[2]

In consideration of existing deficiencies, the present paper undertakes to evaluate published maps of the Ozarks and to

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1. Preston E. James: On the Treatment of Surface Features in Regional Studies, *Annals Ass'n. of Amer. Geogr's.*, Vol. 27, 1937, pp. 213-228.

2. John Leighly: Some Comments on Contemporary Geographic Method, *Annals Ass'n. of Amer. Geogr's.*, Vol. 27, 1937, pp. 125-141; reference is on p. 132.

suggest methods of analyzing and presenting information for the area. The study is based primarily upon work undertaken since June, 1937, but has a background of geographic and geologic field work which was carried on intermittently over a period of years and amounts to at least one full year of investigation.

AVAILABLE MAPS

The Ozark Province is less completely mapped than many other areas. State maps and a few quadrangles present the major facts of areal geology; a number of maps, among which that of Shantz and Zon[3] is outstanding, show the distribution of native vegetation; and topographic sheets, covering most of the area reveal the essential surface characteristics. Many new quadrangles have been published in the last few years, and others are available in preliminary editions. Some of the older topographic maps, however, are inaccurate because of their fifty-foot contour interval and require checking in the field. Soil maps of the Ozarks are inadequate, as they are based on reconnaissance studies and on detailed work in limited areas.

Other maps of importance in a study of the Ozark Province are those of Fenneman[4], Figure 1, Lobeck[5], Figure 2, Sauer[6], Figure 3, and Schottenloher[7]. Fenneman delineates the approximate boundaries of the major physical divisions and describes their physiography; however, he does not indicate minor divi-

3. H. L. Shantz and Raphael Zon: Natural Vegetation, *Atlas of Amer. Agric.*, Pt. 1, Sec. E, 1924; reference is to map preceding p. 6.

4. N. M. Fenneman: Physiographic Divisions of the United States, *Annals Ass'n. of Amer. Geogr's.*, Vol. 18, 1928; reference is to large map in pocket.

5. A. K. Lobeck: A Physiographic Diagram of the United States, A. J. Nystrom and Co., 1921.

6. Carl O. Sauer: The Ozark Highland of Missouri, Univ. of Chicago Press, 1920; reference is to maps on pp. 4,37, and 62.

7. Rudolph Schottenloher: Ozarkland, *Amerikanishe Landschaft*, Erich von Drygalski, editor, Berlin, 1936, pp. 1-125; reference is to Abb. 15, 16, and 17.

Figure 1.

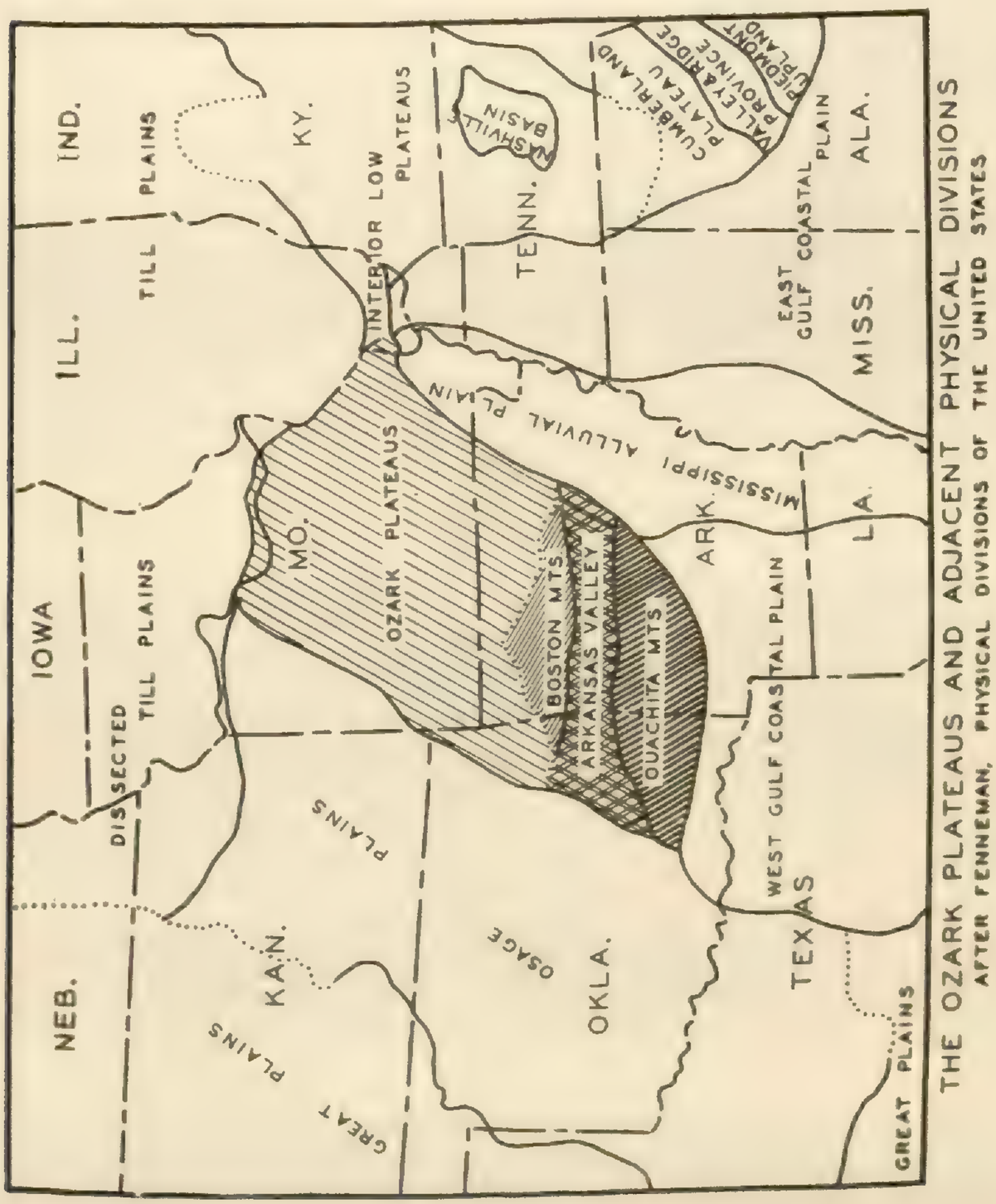
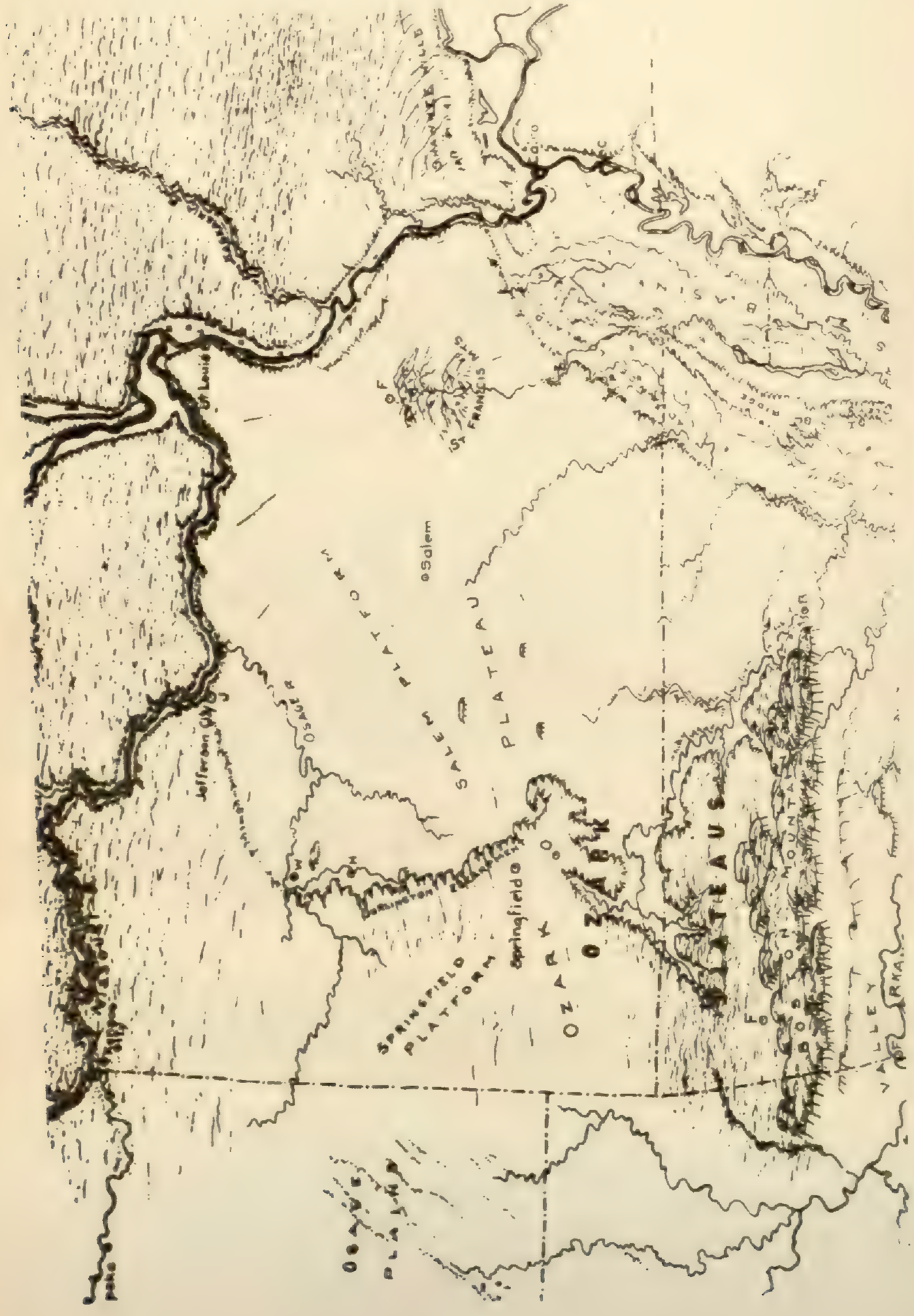

IND.
ILL.
IOWA
NEB.
KAN.
MO.
KY.
TENN.
MISS.
ALA.
ARK.
LA.
OKLA.
TEXAS
TILL PLAINS
DISSECTED TILL PLAINS
INTERIOR LOW PLATEAUS
NASHVILLE BASIN
CUMBERLAND PLATEAU
VALLEY & RIDGE PROVINCE
PIEDMONT PLATEAU
EAST GULF COASTAL PLAIN
MISSISSIPPI ALLUVIAL PLAIN
OZARK PLATEAUS
BOSTON MTS
ARKANSAS VALLEY
OUACHITA MTS
WEST GULF COASTAL PLAIN
PLAINS
GREAT PLAINS
OSAGE
THE OZARK PLATEAUS AND ADJACENT PHYSICAL DIVISIONS
AFTER FENNEMAN, PHYSICAL DIVISIONS OF THE UNITED STATES

Figure 2.



The Ozark Plateaus and Adjacent Physical Divisions, after A. K. Lobeck.

sions. Fenneman's more recent map[8] is essentially the same, except for a slight change in the northern boundary of the Boston Mountains.

Lobeck brings out the relationships between rock structure and topography. He shows clearly the escarpments and dip slopes which are the principal surface features of the asymetrical Ozark dome, but depicts the minor features inaccurately. For example, the rough country surrounding the St. Francis Mountain appears smoother than the Till Plains to the north and east

Sauer represents the several physical factors of the environment separately, thereby facilitating the recognition of relationships. His maps are very good considering the data available, but cover only the Missouri Ozarks and involve a less detailed treatment of the physical landscape than might be desired. The map of surface features[9] is essentially hypsometric because of its large contour interval; a copy of an early Missouri geologic map[10] presents areal geology, many important relationships being brought out in the text; and the treatment of soils is as full as available reconnaissance studies would permit. Sauer's map of geographic regions[11], Figure 3, results from the synthesis of these various factors.

Schottenloher, the most recent writer on the Ozark Province as a whole, has performed an excellent piece of library research, but his work would have been improved by more thorough field study. Three maps, Abb. 15, 16, and 17, present the regional character of the Ozarks. Abb. 15 follows the precedent of

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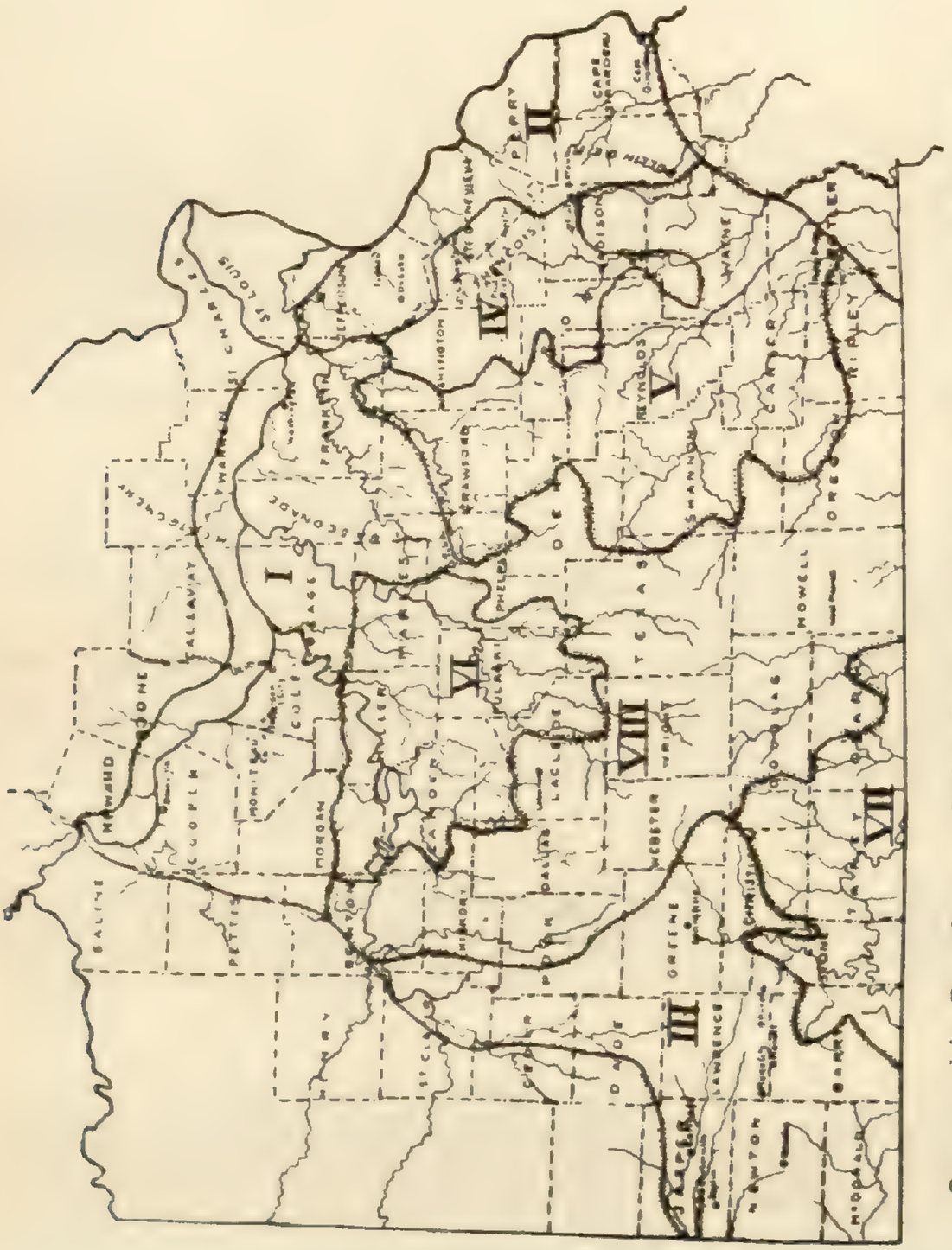
8. N. M. Fenneman: Physiography of Eastern United States, McGraw-Hill, 1938; reference is to Plate VI.

9. Sauer: op. cit.; reference is to map on p. 4.

10. Sauer: op. cit.; reference is to map on p. 37.

11. Sauer: op. cit.; reference is to map on p. 62.

Figure 3.



Geographic Provinces of the Ozark Highland of Missouri. I., Missouri River Border; II., Mississippi River Border; III., Springfield Plain; IV., St. Francois Knob and Basin Region; V., Courtois Hills; VI., Osage-Gasconade River Hills; VII., White River Hills; VIII., Central Plateau. Courtesy of Carl O. Sauer.

Marbut[12] in basing regional distinctions upon dip slopes and escarpments. This map shares with Marbut's the defect of grouping together in one region rock types having distinctly dissimilar topographic, vegetational, and cultural expressions. A case in point is the inclusion in the Potosi Stufenkörper (Salem Plateau) of both the relatively non-cherty Jefferson City-Cotter dolomite and the formations from Potosi through Roubidoux which yield heavy resistant siliceous residuum. A comparison of Figures 5, 7, 8, 9, and 10 will indicate the undesirability of such a grouping. Abb. 16 shows local relief and delineates physiographic regions. However, the relief is stated in general terms and boundaries are extremely indefinite. The physiographic regions are essentially the ones generally recognized, but some with common characteristics are subdivided on the basis of drainage basins, a criterion of doubtful value. Abb. 17 presents the human activities of the various parts of the province.

PRESENT WORK

For purposes of study, the natural environment was analyzed into the usual aspects of geology, climate, physiography, soil, and native vegetation. Of these factors, two, climate and soil, are not treated separately. Climate is important only as it influences the general character of the topography and vegetation; it cannot be a basis of regional differentiation, because of its comparative uniformity throughout the Province. Soil, although important, is treated with geology, because of its close relationship to that factor and because of the paucity of suitable basic information. The other factors, geology, physiography, and native vegetation, are studied in detail, and regions based upon them have been established. A sample region of each type is here described; in every case the area chosen is essentially the same.

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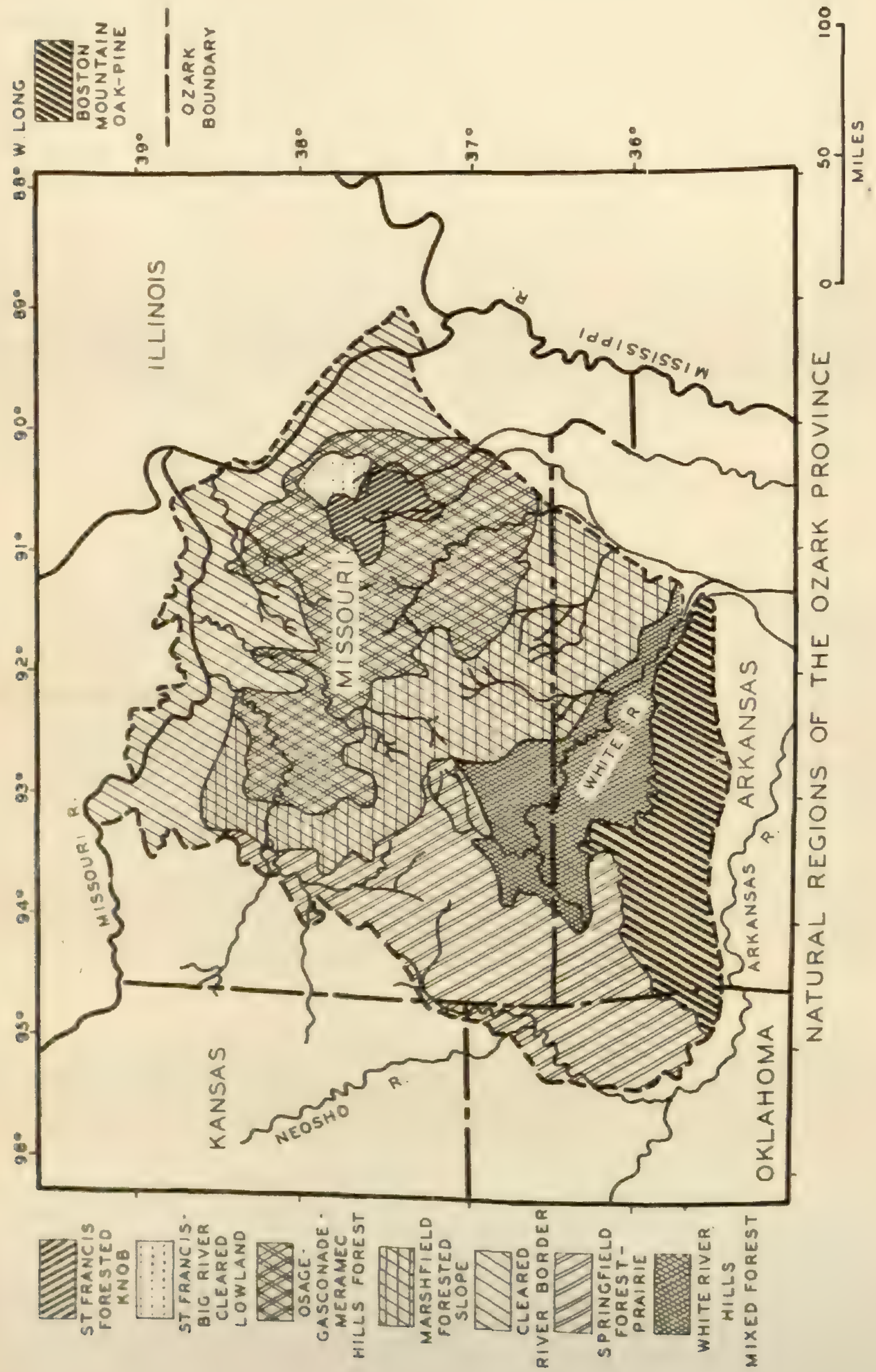
12. Curtis F. Marbut: Surface Features of Missouri, Missouri Geol. Surv. Rept., Vol. 10, 1st Ser., 1896, pp. 14-109; reference is to Plate 2.

Figure 4.


NATURAL REGIONS OF THE OZARK PROVINCE
ILLINOIS
MISSOURI
KANSAS
OKLAHOMA
ARKANSAS
MISSISSIPPI R.
MISSOURI R.
ARKANSAS R.
WHITE R.
NEOSHO R.
88° W. LONG
89°
90°
91°
92°
93°
94°
95°
96°
39°
38°
37°
36°
0
50
100
MILES
BOSTON MOUNTAIN OAK-PINE
OZARK BOUNDARY
ST. FRANCIS FORESTED KNOB
ST. FRANCIS-BIG RIVER CLEARED LOWLAND
OSAGE-GASCONADE-MERAMEC HILLS FOREST
MARSHFIELD FORESTED SLOPE
CLEARED RIVER BORDER
SPRINGFIELD FOREST-PRAIRIE
WHITE RIVER HILLS MIXED FOREST

In mapping and describing the Ozarks, quantitative methods were used wherever practicable; each significant factor of the physical environment was analyzed separately and the results of each study were mapped. Information obtained in this manner has been organized by a combination of analysis and synthesis[13] to develop the natural regions shown in Figure 4.

GEOLOGY

Data obtained from field observations and from geological literature were analyzed into the following significant aspects of bed and mantle rock:

1. Differential resistance to weathering and erosion of any two adjoining rock masses.

2. Order of superposition of resistant (positive) and non-resistant (negative) masses.

3. Structure.

4. Outcrop pattern.

5. Porosity and permeability.

6. Rock type.

7. Absolute resistance of each rock mass.

8. Mineral deposits.

---

13. Synthesis is considered a valid phase of the scientific method, although subordinate to analysis[14]. It is not restricted to art as has been suggested[15].

14. Douglas Johnson: Role of Analysis in Scientific Investigation, *Bull. Geol. Soc. of Amer.*, Vol. 44, 1933, pp. 461-493; reference is on p. 464.

15. John Leighly: Some Comments on Contemporary Geographic Method, *Annals Ass'n. of Amer. Geogr's.*, Vol. 27, 1937, pp. 125-141; reference is on p. 131.

Differential resistance has important influences upon the other aspects of the physical environment. In the Ozarks with their humid continental climate, the action of stream erosion upon the different rocks has produced various topographic expressions. Where the differential resistance between two adjacent rock masses is low, relatively low angles of slope are typical, regardless of the individual durability of the rocks. However, where the differential resistance is high, the land slopes may be either steep or gentle, depending upon the order of superposition of the beds. If a durable stratum overlies a weaker, dissection produces high angles of slope; but if the less resistant is the cap, low angles of slope are typical. In addition to this, the realtive positions of resistant and non-resistant strata influence the rate of topographic development. For example, where the more durable layer forms the cap, level uplands are dissected slowly; whereas, where the weaker layer is uppermost, the uplands soon become rounded and broad valleys may develop.

Structure, together with relative resistance, plays an important part in determining topographic features, patterns of streams and outcrops, and the areal distribution of minerals. Over most of the Ozarks dendritic streams acting upon near-horizontal strata have produced intaglio patterns of outcrops, but in the southeast, steeper dips have resulted in banded outcrops, cuestas, and the rudiments of trellis drainage.

The relative porosity and permeability of bed and mantle rock influence topographic texture, valley forms, and drainage character. Impermeable materials typically develop fine topographic textures; permeable commonly have coarse. Where permeable mantle rock overlies limestone, drainage through the regolith leads to the development of solution valleys which lack permanent surface streams. Permeable bed rock increases subsurface drainage, and, where the rock is soluble limestone, may result in the development of karst topography.

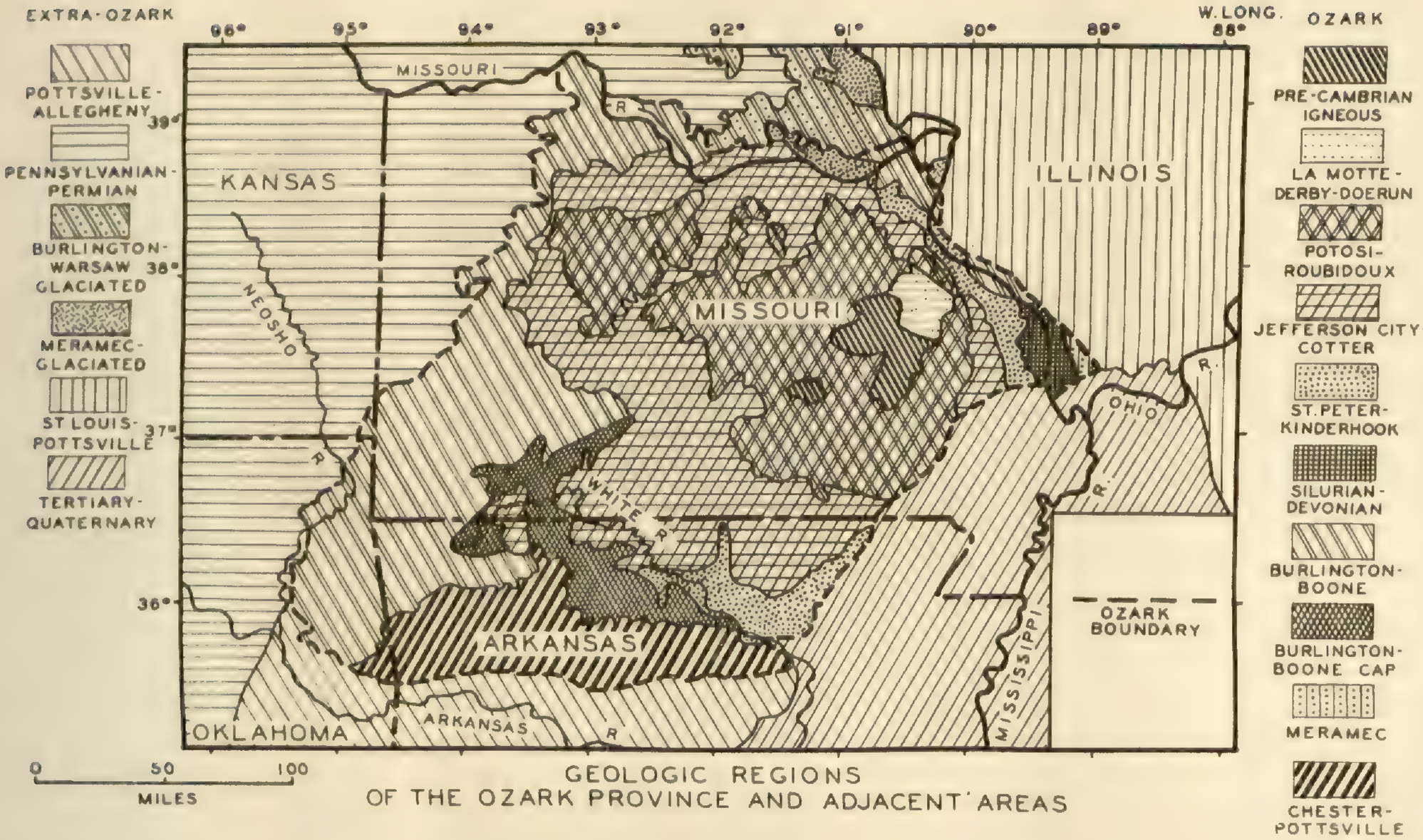
The lithologic type affects weathering, erosion, the development or absence of Karst features, and, in various ways, the distribution of vegetational elements. The two remaining factors, absolute resistance and minerals, are less important than the preceding ones. Absolute resistance may cause regional differences in elevation, and minerals, although important in several parts of the area, have no natural causal influences upon the other factors.

On the basis of the factors just outlined, the Ozarks have been divided into the geologic regions shown in Figure 5. Within each division, the geology is either uniform or uniformly varied, but the geologic age need not be the same throughout. Each region is named for the lowest and highest or, in a few cases, for all stratigraphic units included.

The following description of one region is an illustration of the results obtained by the analysis of the geologic factor. The Burlington-Boone Cap Region is that part of the Springfield Plateau of other writers in which the White and James rivers, acting on near-horizontal strata, have cut through the resistant Burlington-Boone limestone to expose the weaker underlying beds. The rocks of the region differ considerably in their significant characteristics. The Burlington-Boone[16] "formation" consists of massive limestone containing a high percentage of chert as nodules, lenses, and beds. Upon weathering, the limestone dissolves, leaving a deep, pervious, cherty mantle rock which is more resistant than the parent limestone. Because of the pervious character of the residuum, and its occurrence on hilltops, subsurface drainage is rapid and the water table is low. In contrast to the Burlington-Boone the Jefferson City-Cotter[17]

16. The name, Burlington-Boone, is compounded from the names applied to essentially the same strata in different parts of the Ozarks.

17. Jefferson City-Cotter is a formation name compounded as in Burlington-Boone. It is also the name of the geologic region in which these strata, only, are exposed.



GEOLOGIC REGIONS
OF THE OZARK PROVINCE AND ADJACENT AREAS

Figure 5.

dolomite contains very little chert and has moderate absolute resistance. Consequently, it weathers and erodes more rapidly than does the limestone, leaving fine-textured residuum which washes readily on slopes. On hillsides the resulting thin layer of mantle rock is kept moist by horizontal seepage from bedding planes in the dolomite, but on hilltops it is dry, except after rains. The remaining formations of the region, Chattanooga shale, St. Peter sandstone, and Everton limestone, have low to moderate absolute resistance, the Everton being the most durable of the three. Mantle rock derived from these formations is chert free, but varies in character, the Chattanooga and Everton yielding clays and the St. Peter sand.

Deep dissection by dendritic streams has produced a striking intaglio pattern of rock outcrops. The higher hills are capped by Burlington-Boone limestone which is overlaid by its residual chert and rests unconformably upon various other rocks of lower absolute resistance. Of these latter, the Jefferson City-Cotter dolomite has the greatest outcrop area, whereas the other formations, the Chattanooga, St. Peter, and Everton, have more limited exposures within the region.

Probably the most important single factor in the regional complex is the high differential resistance between the Burlington-Boone and the weak beds below it. The order of superposition of the rocks makes differential resistance very effective. The Burlington-Boone chert residuum caps its parent limestone and protects it from erosion, whereas the limestone, itself, acts as a cap for the underlying Jefferson City-Cotter and other weak formations.

Within the Burlington-Boone Cap Regions minerals are unimportant. Sphalerite, smithsonite, and calamine (zinc minerals) occur with galena (lead sulphide) in beds, breccias, and veins in both the Burlington-Boone and the Jefferson City-Cotter formations. These deposits are not being worked at present.

PHYSIOGRAPHY

The physiography of the Ozark Province was analyzed by two methods: first qualitatively, to emphasize recognized physical divisions, and second, quantitatively, to represent objectively the essential characters of the features. A comparison of Figures 6, 7, 8, and 9 show that boundaries determined quantitatively do not necessarily correspond to those on qualitative bases. Finer graduation of the relief and per cent slope scales would permit quantitative expression of observed boundaries, but would yield excessive detail.

The qualitative map, Figure 6, was constructed from data obtained by an automobile traverse which crossed and recrossed the Ozark Province. A comparison of this map with Figure 3, after Sauer, reveals many points of similarity. Furthermore, the regions shown on both maps resemble rather closely the geologic regions, Figure 5, thus emphasizing the close relation between geology and topography.

In constructing the quantitative maps, the method used successfully by Smith for Ohio[18] was found unsuitable because of topographic diversity. Local relief and average slope vary independently from one area to another; hence, both factors must be mapped. A method was devised which accomplishes this and which also adapts itself to different topographic textures.

Local relief was mapped as follows:

1. On all published topographic sheets for the area the relief of each hill was measured from the summit to the lowest point of contact of the slope and a bounding drainage line or level lowland.

2. The values were recorded on the topographic maps, and

18. Guy Harold Smith: The Relative Relief of Ohio, *Geogr. Rev.*, Vol. 25, 1935, pp. 272-284.

boundaries were drawn following drainage lines and other topographic breaks to include areas with relief intervals of 100 feet, the lines being continued from one sheet to another.

3. Lines and relief values were transferred to a 1:1,000,000 base map on which a grid had been drawn to show the location of the topographic sheets.

Slope maps were made to emphasize the high percentage of steep slopes in the Ozarks, the divisions chosen being related to land use as follows:

Slopes of 5 per cent and less (low)—better agricultural land; 6 to 14 per cent inclusive (medium)—typically pasture; 15 per cent and over (high)—commonly wooded. These slope values are higher for corresponding land uses than those obtained by Raisz and Henry in New England[19], due to a number of causes, among which the resistance of the cherty mantle rock to erosion is most important. Angles of slope were expressed in per cent to facilitate visualization and field measurements with a clinometer. For most of the area topographic maps were available and the following procedure was employed:

1. On the topographic sheets, areas of similar physiography were outlined in heavy pencil and boundaries were continued to adjacent quadrangles.

2. Several straight lines were drawn across each area in random directions, traversing physiographic features, as ridges and valleys, approximately at right angles.

3. By means of a dividers and a celluloid scale, on which the spacing of contours for various slopes was shown, measure-

19. Edwin Raisz and Joyce Henry: An Average Slope Map of New England, *Geogr. Rev.*, Vol. 27, 1937, pp. 467-472; reference is to p. 472

Figure 6.

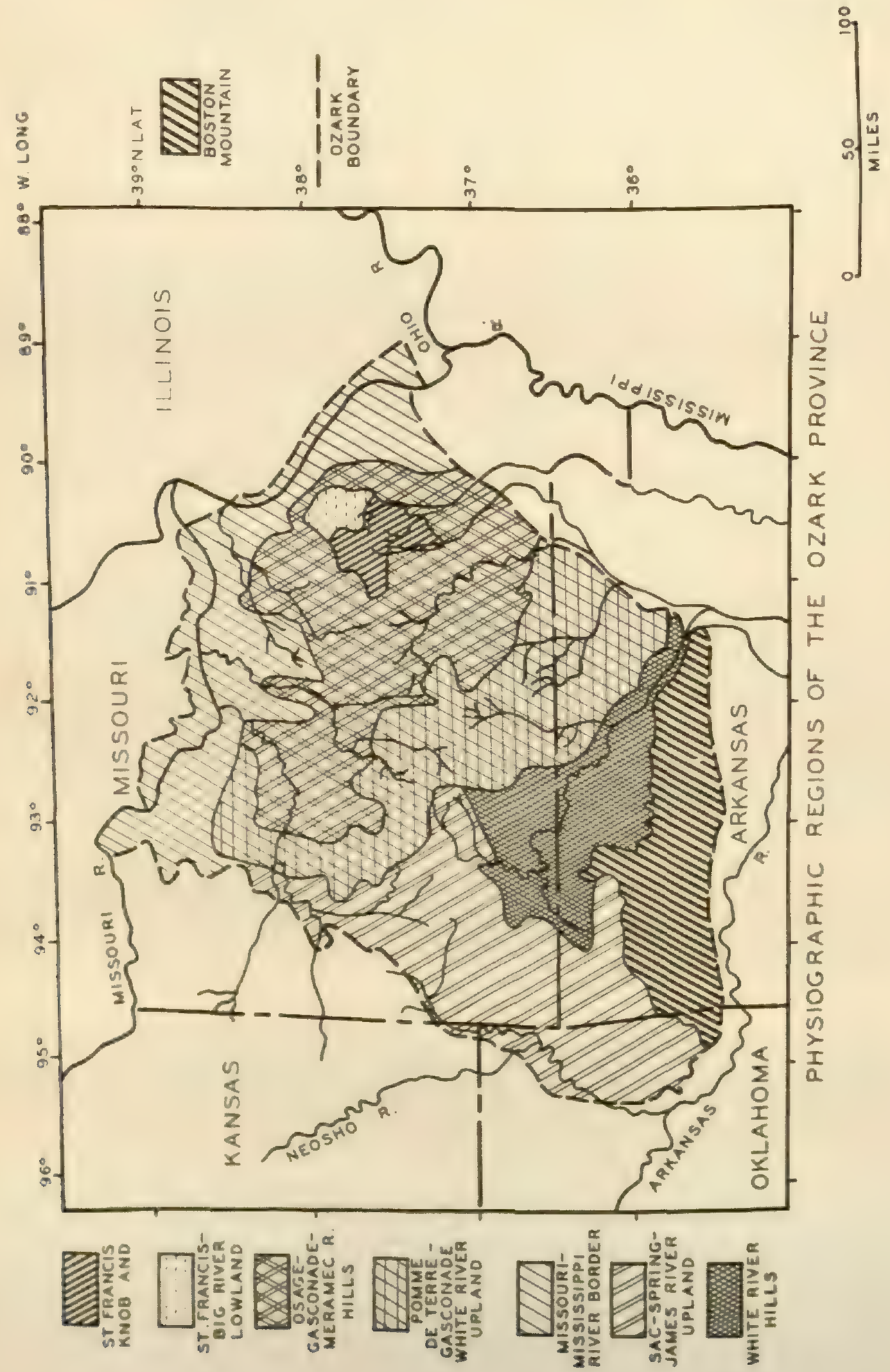

PHYSIOGRAPHIC REGIONS OF THE OZARK PROVINCE
88° W. LONG
89°
90°
91°
92°
93°
94°
95°
96°
39° N LAT
38°
37°
36°
OZARK BOUNDARY
BOSTON MOUNTAIN
ILLINOIS
MISSOURI
KANSAS
ARKANSAS
OKLAHOMA
OHIO R.
MISSISSIPPI R.
MISSOURI R.
NEOSHO R.
ARKANSAS R.
0
50
100
MILES
ST FRANCIS KNOB AND
ST. FRANCIS-BIG RIVER LOWLAND
OSAGE-GASCONADE-MERAMEC R. HILLS
POMME DE TERRE-GASCONADE WHITE RIVER UPLAND
MISSOURI-MISSISSIPPI RIVER BORDER
SAC-SPRING-JAMES RIVER UPLAND
WHITE RIVER HILLS

Figure 7.

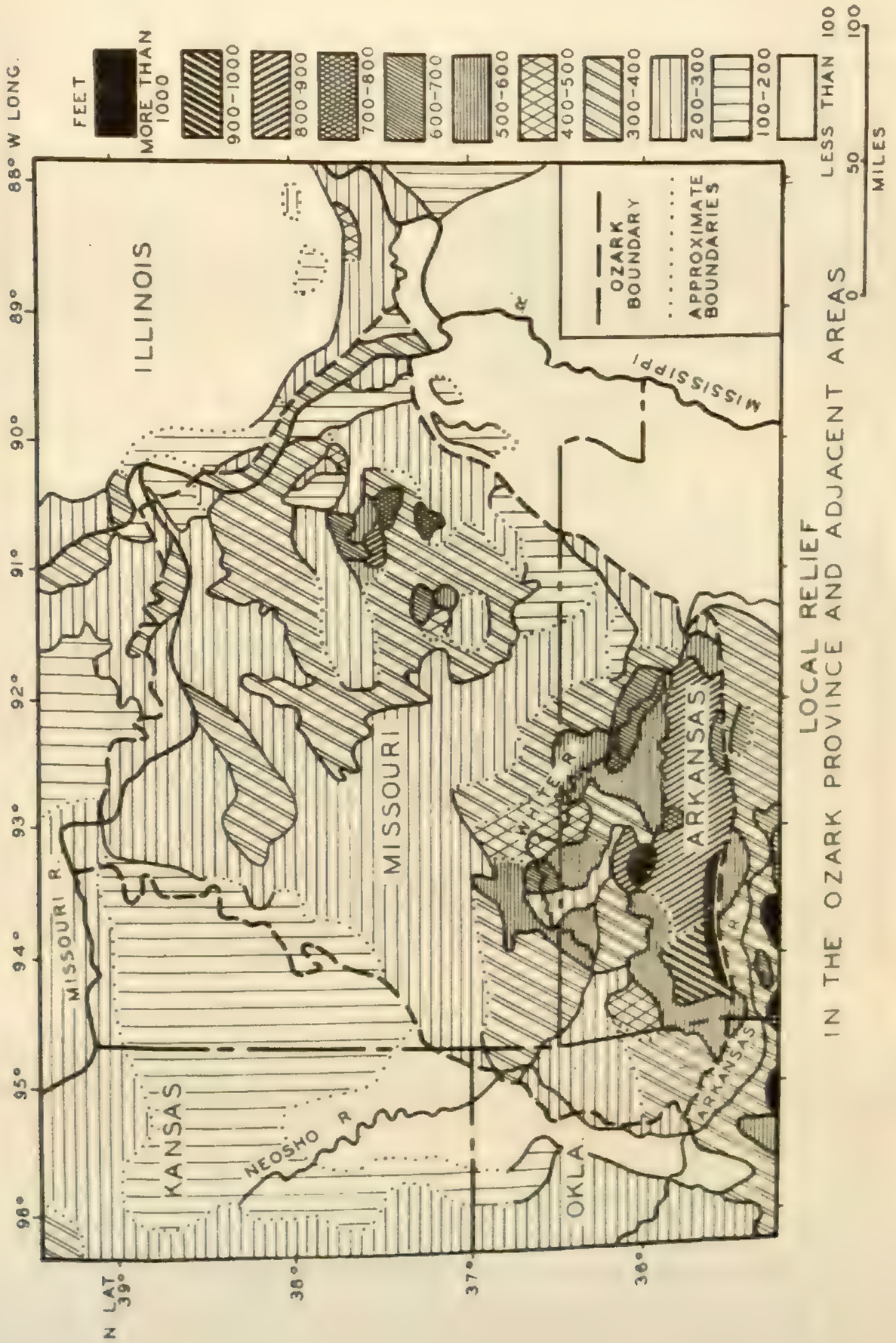

LOCAL RELIEF
IN THE OZARK PROVINCE AND ADJACENT AREAS
FEET
MORE THAN 1000
900-1000
800-900
700-800
600-700
500-600
400-500
300-400
200-300
100-200
LESS THAN 100
0 50 100
MILES
OZARK BOUNDARY
APPROXIMATE BOUNDARIES
ILLINOIS
MISSOURI
ARKANSAS
KANSAS
OKLA
MISSISSIPPI R.
MISSOURI R.
NEOSHO R.
ARKANSAS R.
WHITE R.
88° W LONG.
89°
90°
91°
92°
93°
94°
95°
96°
N LAT
39°
38°
37°
36°

Figure 8.

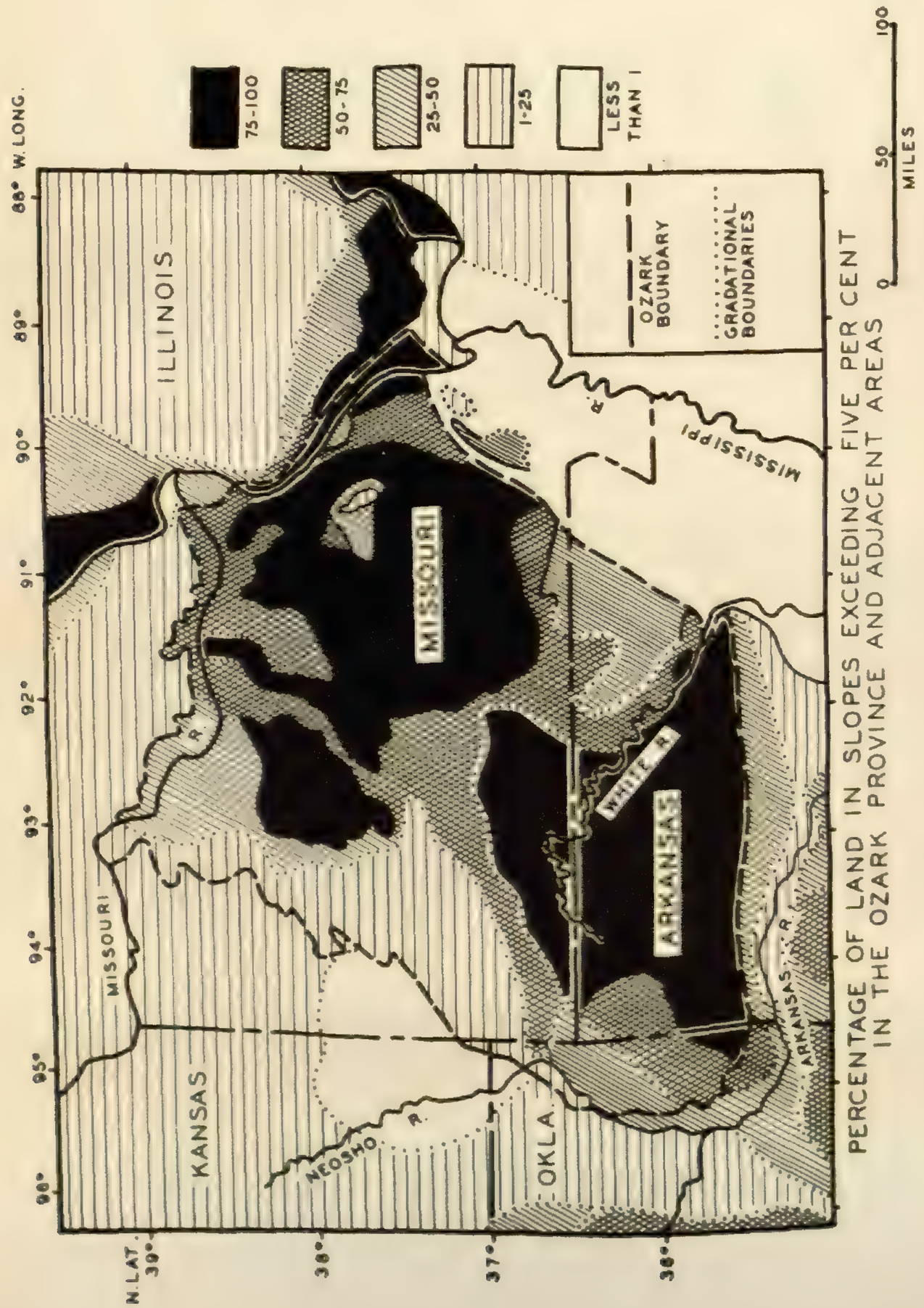
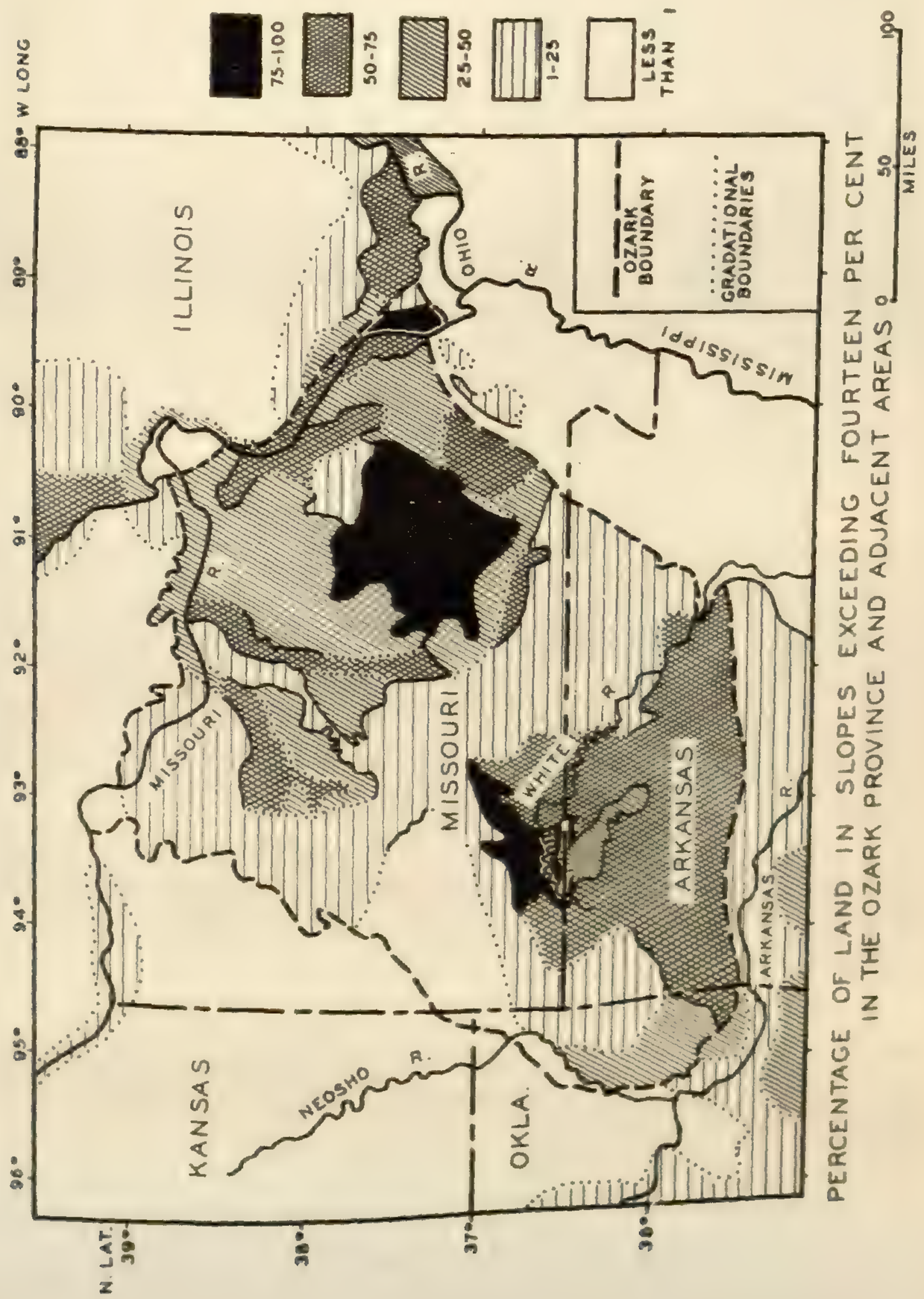

75-100
50-75
25-50
1-25
LESS THAN 1
OZARK BOUNDARY
GRADATIONAL BOUNDARIES
0
50
100
MILES
88° W. LONG.
89°
90°
91°
92°
93°
94°
95°
96°
N. LAT. 39°
38°
37°
36°
ILLINOIS
MISSOURI
KANSAS
OKLA.
ARKANSAS
MISSISSIPPI R.
MISSOURI R.
WHITE R.
ARKANSAS R.
NEOSHO R.
PERCENTAGE OF LAND IN SLOPES EXCEEDING FIVE PER CENT IN THE OZARK PROVINCE AND ADJACENT AREAS

Figure 9.


75-100
50-75
25-50
1-25
LESS THAN 1
OZARK BOUNDARY
GRADATIONAL BOUNDARIES
0
50
100
MILES
PERCENTAGE OF LAND IN SLOPES EXCEEDING FOURTEEN PER CENT IN THE OZARK PROVINCE AND ADJACENT AREAS
ILLINOIS
MISSOURI
ARKANSAS
KANSAS
OKLA.
OHIO R.
MISSISSIPPI R.
MISSOURI R.
WHITE R.
ARKANSAS R.
NEOSHO R.
88° W LONG
89°
90°
91°
92°
93°
94°
95°
96°
N. LAT.
39°
38°
37°
36°

ments were made directly up and down the slopes, and the traverses were divided into the three categories given above. The percentage in each category was then calculated.

4. The values obtained for the traverses were applied to the areas they crossed, and the percentages were recorded on the areas outlined on the map.

5. Boundaries and data for percentages of land in slopes exceeding 5 per cent and for those exceeding 14 per cent were transferred to 1:1,000,000 base maps. No map was made for the percentage of land in slopes 5 per cent and less, as these values can readily be determined from the map of slopes exceeding 5 per cent.

6. In parts of the area for which there were no topographic maps, numerous field measurements were made with clinometer and aneroid barometer.

The White River Hills Region[20], which illustrates the application of the above methods, is one of high steep-sided hills carved from strata of high differential resistance by the White and James rivers. On the south the region is bounded by the Eureka Springs Escarpment and by the north front of the Boston "Mountains". On the northwest the Burlington Escarpment and the continuous cap of Burlington-Boone limestone beyond it mark the line. The north-eastern limit is arbitrary, being based upon decreasing ruggedness. The White River Hills include the Burlington-Boone Cap and parts of the Jefferson City-Cotter and St. Peter-Kinderhook geologic regions[21].

Hills on which the protective caps of Burlington-Boone chert and limestone remain are flat-topped and butte-like, whereas the lower hills of Jefferson City-Cotter dolomite from which the caps

20. Figure 6.

21. Figure 5.

have been eroded have rounded crests. Vestiges of karst topography remain on the higher hills. Moderate to high differential resistance within the Jefferson City-Cotter and between the various formations and members of the St. Peter-Kinderhook Geologic Region has given rise to rock terraces on the hillsides and, in the St. Peter-Kinderhook, to high local relief. Where the Chattanooga shale outcrops below the Burlington-Boone, bluffs develop in the limestone by the undercutting of the shale.

The local relief of the White River Hills Region is mostly between 500 and 600 feet, this being characteristic of the part within the Burlington-Boone Cap Geologic Region. To the northeast the relief decreases with increasing distance from the White River and with the disappearance of the limestone and chert caps from the Jefferson City-Cotter dolomite. The lowest relief, 200 to 300 feet, is in the west where the Jefferson City-Cotter lies uncapped over a small area. In the east, which is included in the St. Peter-Kinderhook Geologic Region, the relief is from 600 to 800 feet and reaches a maximum where small outliers of Burlington-Boone protect the weak St. Peter sandstone near the White River. High and moderate angles of slope (six per cent and more) characterize the White River Hills Region. A study of Figures 6 and 8 shows two definite areas, in one of which 75 per cent or more of the land has these slopes; in the other 50 to 75 per cent. The percentage of land in steep slopes only (15 per cent and more) also is high, usually varying from 25 to 75 per cent plus[22]. Only in the east, the area of highest relief, does the percentage of land in steep slopes fall below 25 per cent.

An attempt to delineate regional boundaries on a quantitative basis shows the impossibility of using the same criteria throughout. The northwestern boundary of this region incloses land of which at least 50 percent is in steep slopes; the north eastern corresponds to the line which includes within its limits areas

22. Figure 9.

with local relief of at least 350 feet; and the southern is indicated throughout most of its length by a sharp change to the higher local relief of 800 feet and over of the Boston "Mountains".

FOREST COVER

The forest cover of the Ozarks was analyzed by calculating the percentage composition of numerous woods growing under definite conditions of slope, exposure, bed and mantle rock. Because of the patchy accidental distribution of the different species, the method of analysis by linear traverse was chosen. Each traverse had the same general trend throughout, but deviated sufficiently to follow the pattern of the ridges and to avoid changes in conditions. The count was made by two persons, an observer, who identified the trees, and a recorder, who tallied the various species. The observer stood in one place until the trees for about 75 yards on either side and in front had been counted, then advanced to the farthest tree counted and repeated the process. Wherever possible, the traverses were a mile or more long to include at least 500 trees. Percentages were calculated with a slide rule. From the data so obtained forest types were distinguished and a forest cover map, Figure 10, was made on the bases of:

1. Dominant species — the more abundant species which, collectively, constitute more than 50 per cent of the forest.

2. Indicators — species characteristic of definite bed and mantle rock.

3. Present size and quality of the timber.

4. Approximate percentage of the area in forest.

This classification somewhat resembles that proposed by the American Society of Foresters[23].

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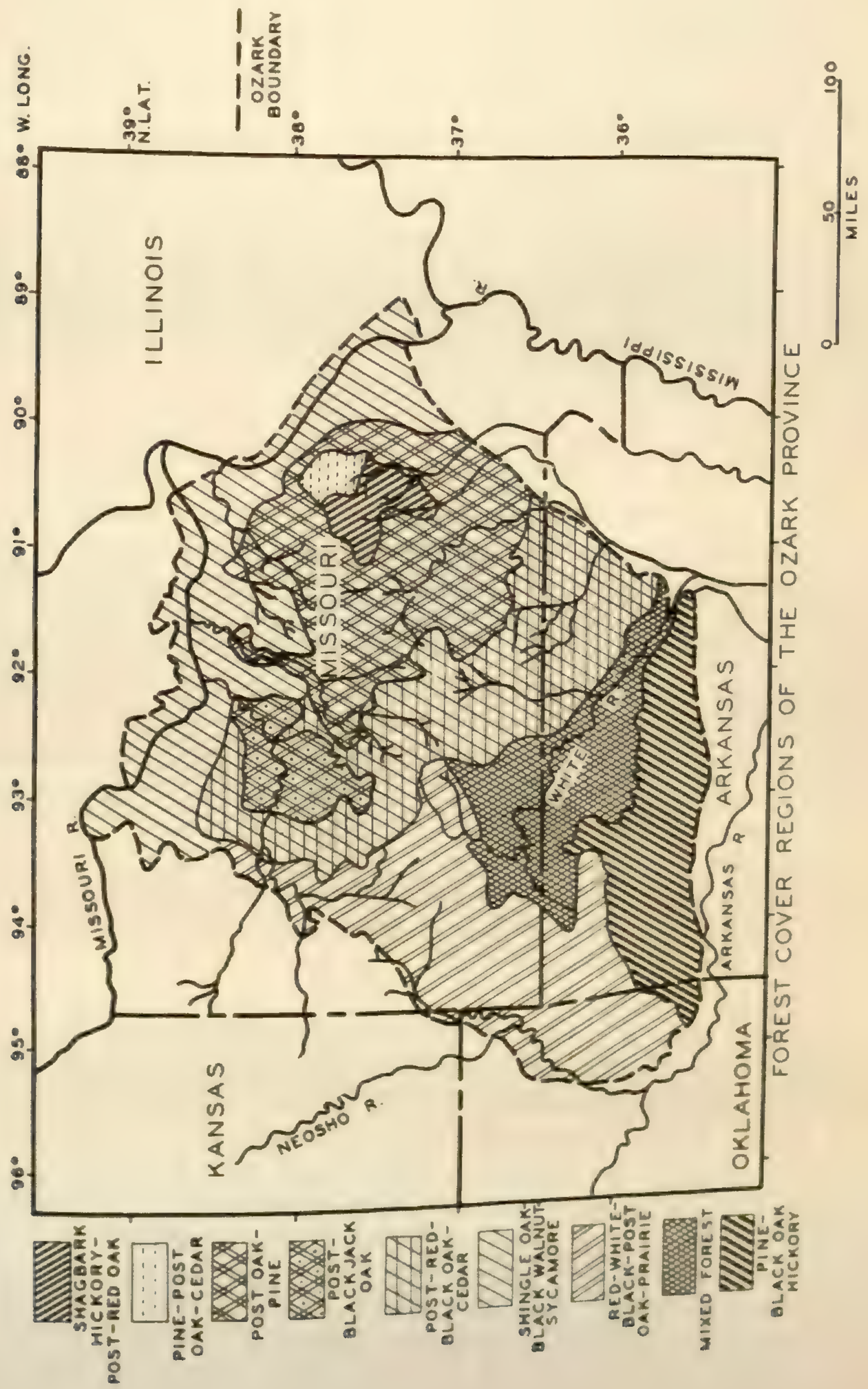
23. Amer. Soc. of Foresters: Forest Cover Types of the Eastern United States, *Journ. of Forestry*, Vol. 30, 1932, pp. 451-498.

Figure 10.


88° W. LONG.
89°
90°
91°
92°
93°
94°
95°
96°
39° N.LAT.
38°
37°
36°
OZARK BOUNDARY
ILLINOIS
MISSOURI
KANSAS
OKLAHOMA
ARKANSAS
MISSISSIPPI R.
MISSOURI R.
WHITE R.
ARKANSAS R.
NEOSHO R.
0
50
100
MILES
FOREST COVER REGIONS OF THE OZARK PROVINCE
SHAGBARK HICKORY-POST-RED OAK
PINE-POST OAK-CEDAR
POST OAK-PINE
POST-BLACKJACK OAK
POST-RED-BLACK OAK-CEDAR
SHINGLE OAK-BLACK WALNUT-SYCAMORE
RED-WHITE-BLACK-POST OAK-PRAIRIE
MIXED FOREST
PINE-BLACK OAK HICKORY

The results of the analysis indicate that definite relationships exist between bed rock and the percentage composition of the associated forest[24], but most of these relationships appear to be indirect. Many species of trees occur throughout the area, the woods on dissimilar rock types differing chiefly in the relative abundance of the various species. The greatest differences in the forest composition exist between woods growing in unlike topographic situations rather than between woods similarly situated but on different rocks. This strongly suggests that bed and mantle rock, while exerting some direct influence on the nature of the forest, especially on indicators, function as controls principally through the media of slope, drainage, and exposure to sunlight.

Within the Ozarks there are some broad, gradual vegetational transitions which bear no apparent relation to the bed and mantle rock. The diversity of the forest decreases from southeast to northwest, due to increasing climatic severity and to greater distance from the Gulf Coastal Plain, the source of many of the forest elements. In general, the Ozarks are forested with a dense growth of small trees averaging thirty feet in height, but including some larger trees remaining from a former open, grassy woodland. The small size of the timber is due primarily to the extremely slow growth of the most abundant species, the post oak, and to selective cutting of the larger and more desirable trees.

The Mixed Forest Region[25], the example chosen, includes several distinct vegetational assemblages, each of which is associated with a definite bed rock type. On the Burlington-Boone caps of the higher hills the forest is dominated by red, white, and black oaks which collectively constitute over 50 per cent of the timber. Southern pine is the indicator and locally is the most abundant species. The oak assemblage indicates soil fertil-

24. Compare Figures 5 and 10.

25. Figure 10.

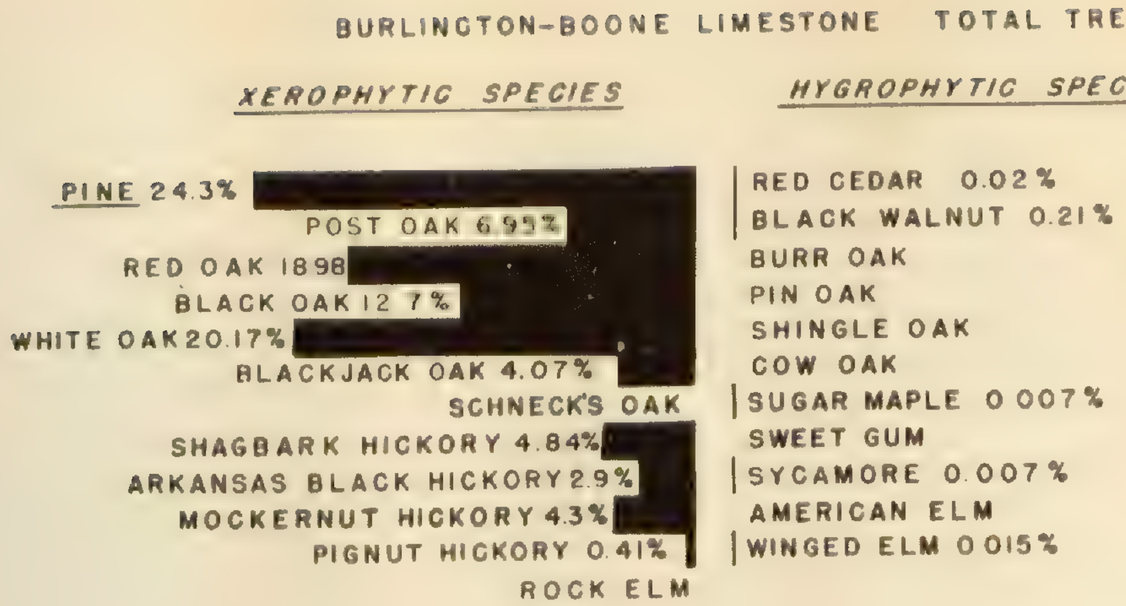
ity above the average for the Ozarks, and the presence of abundant pines reflects the influence of the low water table in the pervious chert residuum.

On the Jefferson City-Cotter dolomite of the lower hills the vegetation is characteristic of poor shallow soil derived from non-cherty dolomite and of abundant moisture which seeps out between the strata of the bed rock. Post, red, and black oaks are the dominant species and southern red cedar is the indicator. The timber is smaller than that on the Burlington-Boone, principally because the shallow soil does not afford adequate root anchorage for large trees. Many small patches have soil so thin that only grass, herbaceous plants, and small cedars thrive. These barrens are called glades or, if on hilltops, bald knobs.

A comparison of two adjacent woods four miles north of Forsyth, Missouri, Figure 11, emphasizes the essential differences between the forest on the Burlington-Boone and that on the Jefferson City-Cotter[26]. In each case the percentage of the indicator (pine or cedar) is abnormally high. The line between the two vegetational assemblages is extremely sharp. Neither pines nor cedars transgress the boundary more than a few feet,

---

26. In calculating the percentage composition of the forests on each rock type, it was necessary to estimate the percentage of the total stand in each situation, as summits, west-facing slopes, east-facing slopes, and so on, and to qualify the count obtained for each situation in the light of this estimate. The tree counts on north-, south-, east-, and west-facing slopes were given equal values in both calculations, but the numerical relation between forests on slopes and those on summits was different for the two rock types. For the Burlington-Boone forests, the number of trees on slopes was estimated to be three times as great as the number on level summits. For the Jefferson City-Cotter forests, however, it was estimated to be four times as great. In neither case were the forests of the flood plains included, as these appear to be influenced very slightly, if at all, by the nature of the bed rock. These lowland forsets vary gradually from place to place, according to climatic variations and to position with relation to the source of forest elements migrating into the region. The figures given in Figure 11 represent actual tree counts; the percentages are based on calculated values.



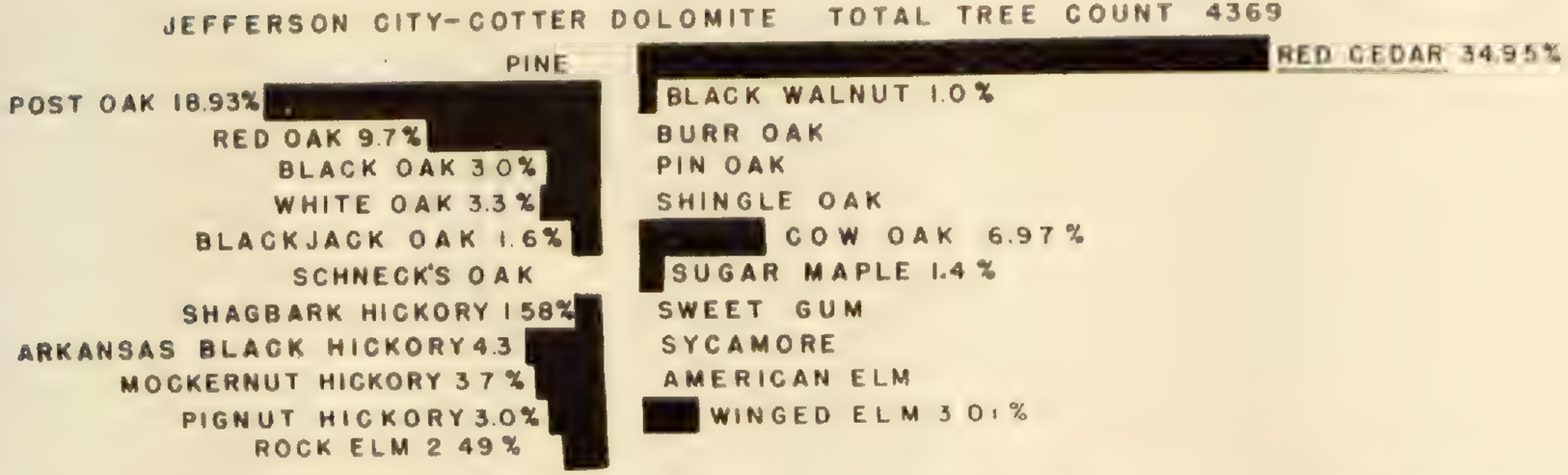


Figure 11.

Percentage Composition of Adjoining Woods on Burlington-Boone Limestone and Jeferson City-Cotter Dolomite.

and the general character of the forest on each rock type is distinctive.

The other rock formations of the region present only limited opportunities for study of their associated forests because of their small outcrop areas. No count was obtained for the Chattanooga shale or for most of the formations of the St. Peter-Kinderhook Geolgic Region. On the St. Peter, however, the forest is similar to that on the Burlington-Boone. Shortleaf pine, red and black oaks are the dominant species and pine is the indicator.

CONCLUSION

This study of the Ozark Province is offered as one more bit of evidence favoring the regional treatment of natural landscapes. The close relationships existing among the various environmental factors render the province an especially suitable example. During the long period of erosion which the area has experienced, the streams have discovered the dissimilarities of lithology and structure resulting in the development of distinctive physiographic types. Geology and vegetation, likewise, have shown themselves to be closely connected through the media of residual soils and of topography which influences drainage and exposure.

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VOLUME XXX, No. 3

THE CYTOLOGICAL STRUCTURE OF THE HYPOTHALAMIC NUCLEI IN RELATION TO THEIR FUNCTIONAL CONNECTIONS

HOMER DALE KIRGIS

St. Louis University School of Medicine

Issued May 31, 1940

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VOLUME XXX, No. 3.

The Cytological Structure of the Hypothalamic Nuclei in Relation to Their Functional Connections

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The Cytological Structure of the Hypothalamic Nuclei in Relation to Their Functional Connections

Homer Dale Kirgis

Most investigations of the structure of the hypothalamus have been devoted to the division of this region of the brain stem into its various nuclei or the functional connections of these nuclei. In most of the early work, the identification of the nuclei was based on cell types. In the more recent studies, nuclei have been named on the basis of their relative isolation by fiber tracts or undifferentiated gray matter. Malone (1913), Greving (1923), and Gagel (1928) have pointed out certain relationships between the cytological structure of nerve cells and their particular functions.

In correlating structure and function of nerve cells Jacobshon (1910) pointed out that as the general body structure becomes increasingly specialized in the higher members of the

phylogenetic series, the motor neurons in the nervous system become correspondingly better developed.

Malone (1912) pointed out that the neurons whose axons end in relation to the peripheral somatic motor neurons are very similar to the latter in structure. The structural features of somatic motor neurons are large size, polygonal form, and a chromidial pattern made up of rather large granules which are relatively regular in outline and uniformly distributed in the cytoplasm. He (1913) also asserted that the neurons whose axons supply skeletal muscle may be differentiated from visceral motor neurons by their cytological characters. Malone (1929) pointed out further that diffuse distribution of the chromidial substance is characteristic of afferent neurons, but efferent neurons with increased integrating capacity exhibit concentration of the chromidial substance into distinct granules and groups of granules. According to his findings the distribution of chromidial granules in distinct, separate units is related to the capacity of the neurons to integrate impulses from many diverse sources rather than to the volume of impulses received. He reported that the preganglionic visceral neurons are cytologically similar to the premotor neurons. Of all the preganglionic visceral neurons, those of the dorsal vagus nucleus which supply cardiac muscle most closely approach the cytological structure of somatic motor neurons. These neurons have a smaller cell body, fewer and shorter dendrites, and a chromidial pattern in which aggregates of granules usually do not appear as distinct units. Like the motor neurons, they are polyhedral in form, but the less specialized visceral efferent neurons exhibit rounded forms. The latter also possess fewer dendrites and a chromidial pattern in which the granules are much less discreet. According to Malone, the cytological structure of these neurons is correlated with the relative simplicity of visceral reactions.

Von Lenhossék (1887) was among the first to describe nuclei in the hypothalamus. He delimited the nucleus supraopticus and two nuclei in the tuber cinereum in man. One of the latter

is the large anterior nucleus which occupies the greater portion of the tuber cinereum; the other the relatively minute postero-lateral nucleus. In a fundamental study of the hypothalamus in man, Malone (1910) recognized seven nuclei on the basis of the cytological structure of their constituent neurons.

Greving (1923) discussed the fiber tracts related to the hypothalamic nuclei, as observed in Bielschowsky preparations. Later (1928), he described seven nuclei in the tuber cinereum in the human hypothalamus and seven more in the mammillary body and neighboring regions. In an extensive study of the hypothalamus in the albino rat, reported in a series of papers, Gurdjian (1925, 1926, 1927) described various fiber connections of the hypothalamic nuclei and classified these nuclei mainly on the basis of their relative isolation by fiber tracts or undifferentiated gray matter. By using the delimitation of neuron groups as a criterion, in contrast to the criterion of cell types used by Malone, Rioch (1929) was able to identify twenty nuclei in the hypothalamus in the dog and the cat.

Grünthal (1929) found the nuclear pattern in the hypothalamus in the dog similar to that in the rat, but somewhat simpler. He (1930) also reported that the lower mammals present a more complex nuclear pattern in the hypothalamus than the more highly specialized ones. This, according to his observations, is true also in human ontogeny, that is, there is a progressive simplification of the nuclear pattern as the human embryo develops. He observed more nuclear divisions in the embryo than in the newborn.

According to Morgan (1930) the neurons of the substantia grisea centralis are among the smallest nerve cells in the central nervous system and the smaller cells preponderate in the immediate vicinity of the third ventricle and in the areas in which the neurons are thinly scattered. The larger ones are found particularly in those areas in which the neurons are most densely aggregated. Morgan agreed with Malone that, although the

neurons of the substantia grisea centralis vary in size in different areas and are more densely packed in some regions than in others, they probably all represent one functional type and should be considered as incorporated in a single nucleus. On the basis of a study of the hypothalamus of the albino rat, Krieg (1932) concluded that the nuclei filiformis, supraopticus, lateralis, praemammillaris lateralis, and mammillaris lateralis appear to consist of cells of the autonomic type.

Ingram et al (1932) described nineteen groups of cells in the hypothalamus of the cat. Crouch (1934) reported twenty-one nuclei in the hypothalamus of Macacus rhesus. He found that the nuclei are not as clearly set off from neighboring groups in Macacus rhesus as they are in lower mammals but most of the nuclei are homologous to the corresponding hypothalamic nuclei of lower mammals.

The present work has been undertaken to examine the nuclei of the hypothalamus of the cat which have been identified on the basis of their separation from neighboring nuclei and point out the correlation between the cytological structure of their constituent neurons and the functions which they must subserve because of their anatomical connections.

MATERIALS and METHODS

The present investigation is based on serial sections of the brain stems of cats, cut to a thickness of eight microns. The material was fixed in a forty percent aqueous solution of mercuric chloride. Fixation was facilitated by transfusion with the fixative through the common carotid artery of the freshly killed animal. After two hours the brain was removed and the portion of the brain stem in question placed in the fixative for two days.

At the end of this period it was removed, dehydrated, embedded, and sectioned.

The sections were stained with toluidin blue and erythrosin. Very satisfactory results were obtained, particularly with regard to the chromidial pattern, by staining the mounted sections for three minutes in a one per cent solution of erythrosin and then for seven minutes in a saturated solution of toluidin blue. Destaining to the desired degree was accomplished as the tissues were passed through the series of alcohols preparatory to covering.

MICROSCOPIC OBSERVATIONS

The hypothalamic nuclei in the cat are made up mainly of small or medium-sized neurons. Although there is great similarity in the structure and morphology of the neurons in the different nuclei, it is fairly easy by careful study to identify these nuclei because of small areas of relatively undifferentiated gray matter and fiber tracts between them. The identity of most of the hypothalamic nuclei, however, could be established by their cytological structure even in the absence of such separation from neighboring nuclei. Variations in the cytological structure of the neurons of different hypothalamic nuclei have been pointed out by Malone (1912, 1913, 1914) and others, but all of the neurons of the hypthalomic nuclei in the cat can be classified in four general categories on the basis of chromidial pattern and general morphology. These categories have been named according to the synaptic connections of their constituent neurons: peripheral visceral efferent, central somatic efferent, central visceral efferent, and associational.

The peripheral visceral efferent neurons (Fig. 1 A) are those which, although located centrally, effect functional connections with cells in the posterior lobe of the pituitary gland. They are

located mainly in the nucleus supraopticus but some occur also in both the nucleus filiformis principalis and the nucleus filiformis lateralis. They are relatively large polyhedral neurons. The chromidial pattern consists of a complete or partially complete peripheral ring of coarse chromidial granules and very fine chromidial dust in the remainder of the cytoplasm.

The central somatic efferent neurons (Fig. 1 B) exhibit a chromidial pattern which is comparable to that of neurons which are known to make synaptic connections with the motor neurons of the cranial nerves or those in the anterior horn in the spinal cord. Neurons of this type occur in the lateral hypothalamic, the lateral mammillary, and in the dorsal hypothalamic nuclei. The chromidia are relatively coarse and are diffusely distributed throughout the cell body, including the expanded proximal portions of the dendrites. Most of these neurons are polyhedral in form but some are roughly spherical. In general they are very similar to somatic motor neurons.

The central visceral efferent category includes the neurons (Fig. 2 A) whose axons terminate in relation to neurons of the general visceral efferent column of the brain stem or the intermediolateral cell column of the spinal cord. The central visceral efferent neurons vary in size but their general cytological structure is remarkably constant thoughout the hypothalamus. The smaller ones tend to be spherical and the larger ones polyhedral. The chromidia are irregular in shape and, in general, form a diffuse peripheral ring, but they may tend to be aggregated in certain areas of the cytoplasm. Most of the hypothalamic nuclei of the cat contain neurons of this type.

The associational category includes those very small neurons (Fig. 2 B) of the hypothalamus which are comparable both in size and cytological structure to the associational neurons in the spinal cord. They make local connections. In general, the cell body is spherical but may be slightly fusiform. The relative amount of chromidial substance varies in different nuclei but the

pattern is quite uniform. The chromidia are finely granular and, in most of these neurons, form a very compact perinuclear ring. They rarely have a peripheral distribution.

HYPOTHALAMIC NUCLEI MADE UP CHIEFLY OF PERIPHERAL VISCERAL EFFERENT NEURONS

Nucleus Supraopticus: This nucleus is located ventrolaterally in the rostral portion of the hypothalamus (Fig. 3 A), just dorsal to the fibers of the optic tract. Is is divided, throughout most of its extent, into a lateral, large-celled portion, and a medial, medium-sized and small-celled portion. The lateral division includes the greater part of the nucleus and contains the peripheral visceral efferent neurons. The larger neurons of the medial division are central visceral efferent; the smaller ones are associational. The neurons of the large, lateral divisions are regarded as those whose axons form the supraoptico-hypophyseal tract.

Nucleus Filiformis Principalis: The main body of this nucleus lies in the medial portion of the tuber cinereum a short distance lateral to the third ventricle (Fig. 3 B). The neurons are not compactly aggregated, particularly in the anterior part of the nucleus where most of them are in other respects identical to those of the lateral portion of the nucleus supraopticus, but slightly smaller central visceral efferent and associational neurons occur among those of the peripheral visceral efferent type.

Nucleus Filiformis Lateralis: This nucleus lies lateral to the dorsal tip of the nucleus filiformis principalis and is separated from the latter by undifferentiated periventricular gray matter. The presence of peripheral visceral efferent neurons suggests functional connections similar to those of the lateral portion of the nucleus supraopticus. These neurons are somewhat smaller than the peripheral visceral efferent neurons in the supraoptic nucleus and the chromidial dust in them is less marked. Central visceral efferent and associational neurons also are present.

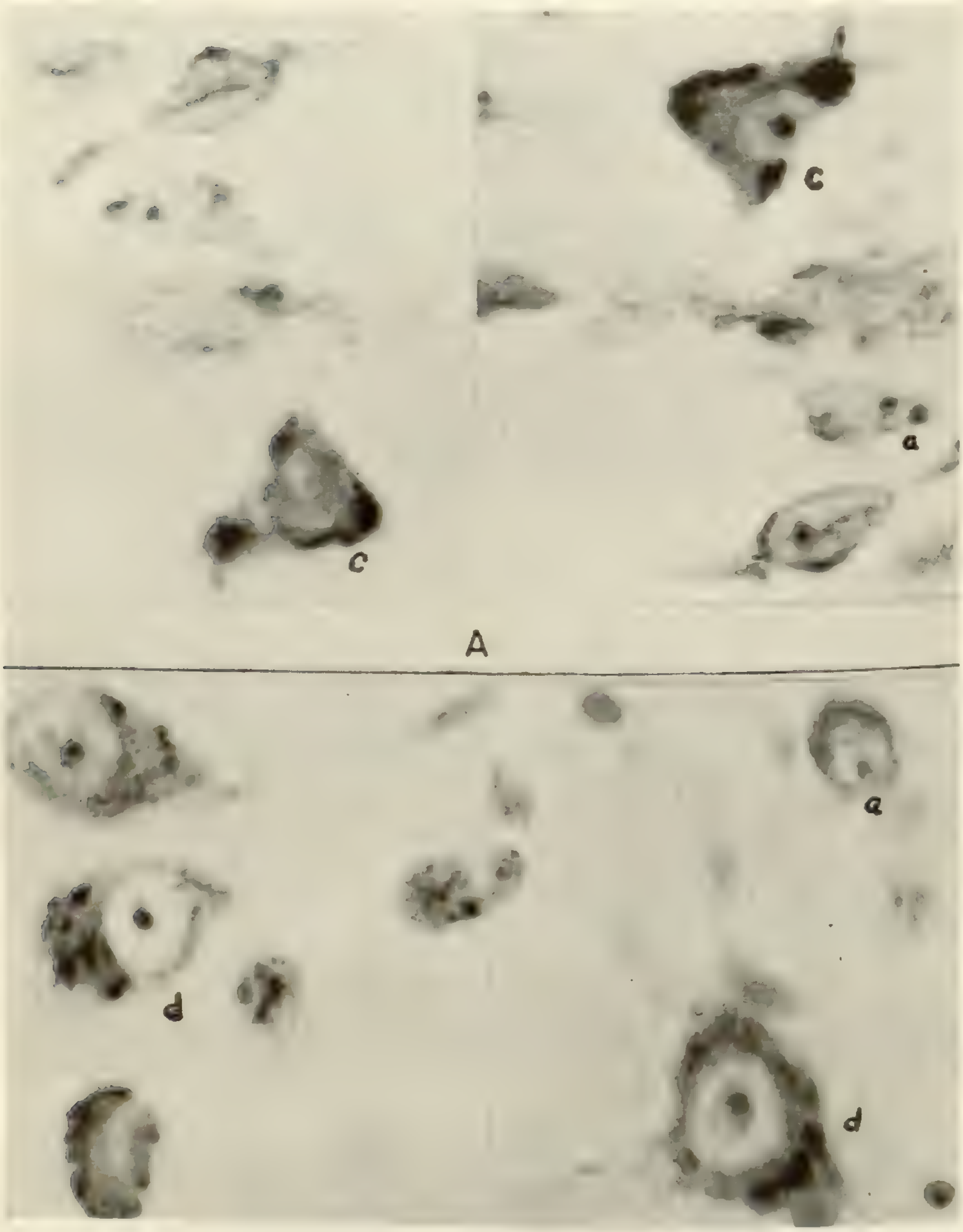


Figure 1. A-c, Peripheral visceral efferent neuron.
A-a, Associational neuron.
B-d, Central somatic efferent neuron.

Hypothalamic nuclei containing central somatic efferent neurons

Nucleus Hypothalamicus Lateralis: The neurons of this nucleus are somewhat scattered but form a fairly definite aggregate which extends throughout most of the lateral portion of the tuber cinereum and lies lateral and dorsolateral to the fibers of the medial forebrain bundle (Fig. 3 A). The central somatic efferent neurons are not segregated but lie among the central visceral efferent and associational neurons which form a part of the nucleus. According to Malone (1912), the neurons in this nucleus which are similar cytologically to somatic motor neurons are continuous caudally with the superior colliculus and the reticular substance of the brain stem.

Nucleus Mammillaris Lateralis: This nucleus is located along the ventral margin of the mammillary body just lateral to the medial mammillary nucleus (Fig. 3 D). Nearly all of its constituent neurons are of the central somatic efferent type. They tend to be a little less polyhedral and more spherical than those of the nucleus hypothalamicus lateralis. Both with respect to morphology and chromidial pattern they are very similar to the motor cells of the anterior horn in the spinal cord. Some central visceral efferent and associational neurons are present.

Nucleus Hypothalamicus Dorsalis: This is a diffuse mass of neurons found in the dorsal part of the posterior portion of the tuber cinereum (Fig. 3 B). It is bounded medially by the third ventricle and laterally, in part, by the mammillo-thalamic tract. The central somatic efferent neurons which are present are very similar to typical anterior horn cells, but they are relatively few in number. The great majority of the neurons are of the associational and central visceral efferent types. Those of the latter type contribute fibers to the periventricular system (Gurdjian, 1927).

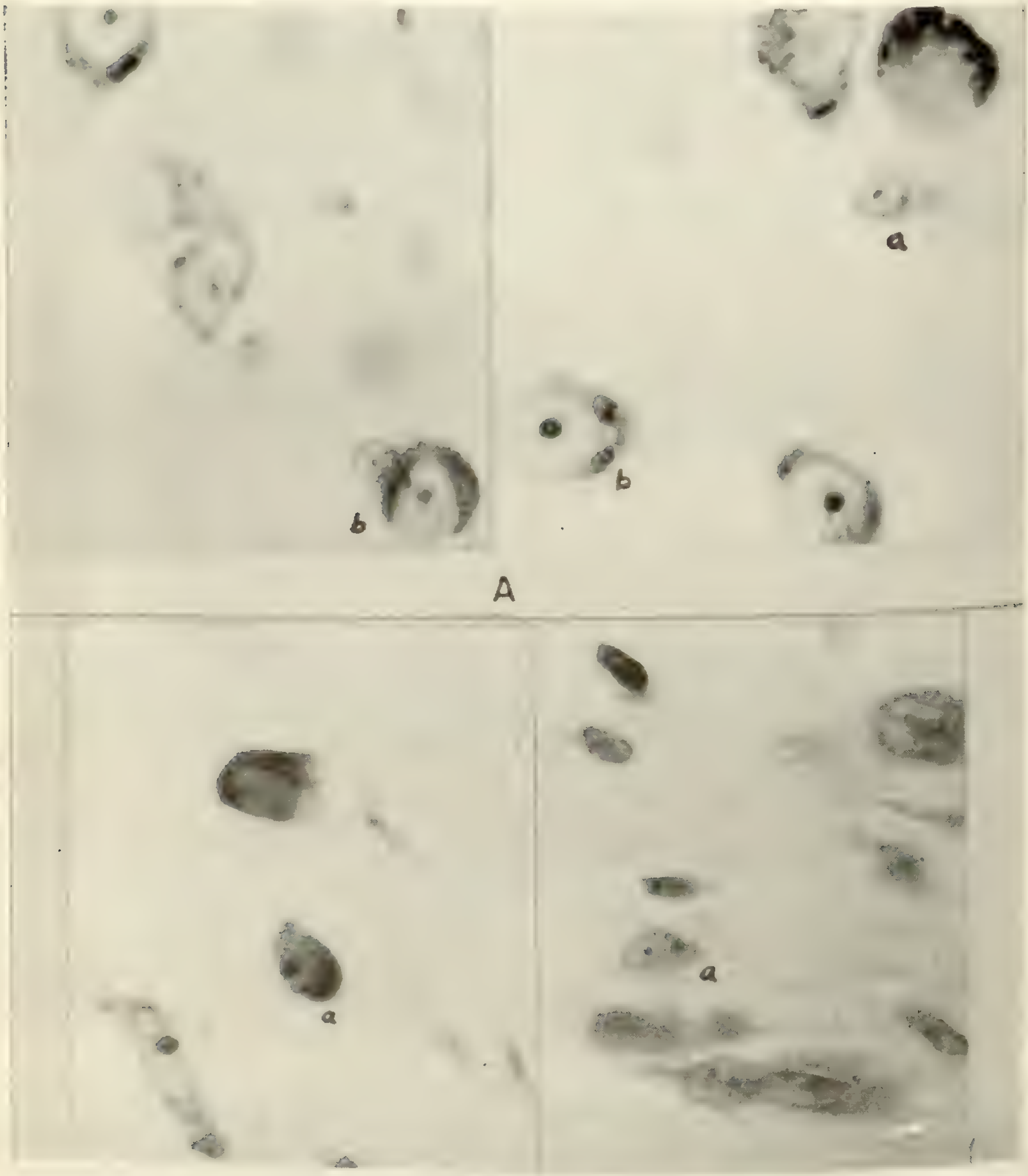


Figure 2. A-b, Central visceral efferent neuron.
A-a, Associational neuron.
B-a, Associational neuron.

Hypothalamic nuclei made up chiefly of central somatic efferent neurons

Nucleus Hypothalamicus Dorsomedialis: This nucleus lies lateral to the third ventricle (Fig. 3) and is most apparent just anterior to the middle of the tuber cinereum. Its boundaries are not clearly defined, particularly with reference to the nuclei in the anterior hypothalamic area and the nucleus filiformis principalis. Its constituent neurons are central somatic efferent and associational; the former being much the more abundant. Many of the central somatic efferent neurons are slightly fusiform and are oriented so that the long axis lies parallel to the wall of the third ventricle. The nuclei of all the neurons of this group are characterized by very little chromatin except that of the nucleolus. This gives the group as a whole a relatively clear appearance. Efferent fibers arising in this nucleus enter the periventricular system (Gurdjian, 1927; Krieg, 1932).

Nucleus Hypothalamicus Ventromedialis: The dorsal portion of this nucleus fuses with the nucleus hypothalamicus dorsomedialis (Fig. 3 A). The nucleus hypothalamicus periventricularis ventralis and the nucleus hypothalamicus periventricularis dorsalis form its medial boundary throughout part of its extent. The component neurons are central somatic efferent and associational. The former form the greater part of the nucleus. They are peculiar for neurons of this type in that the processes are relatively very coarse, and considerable chromidial substance extends into the proximal portion of these large processes. The cell body also contains a slightly larger amount of chromidial substance than is seen in typical central somatic efferent neurons. These structural peculiarities suggest that the functional connections of these neurons may be effected at a greater distance from the hypothalamus. The distribution of their axons has not been determined.

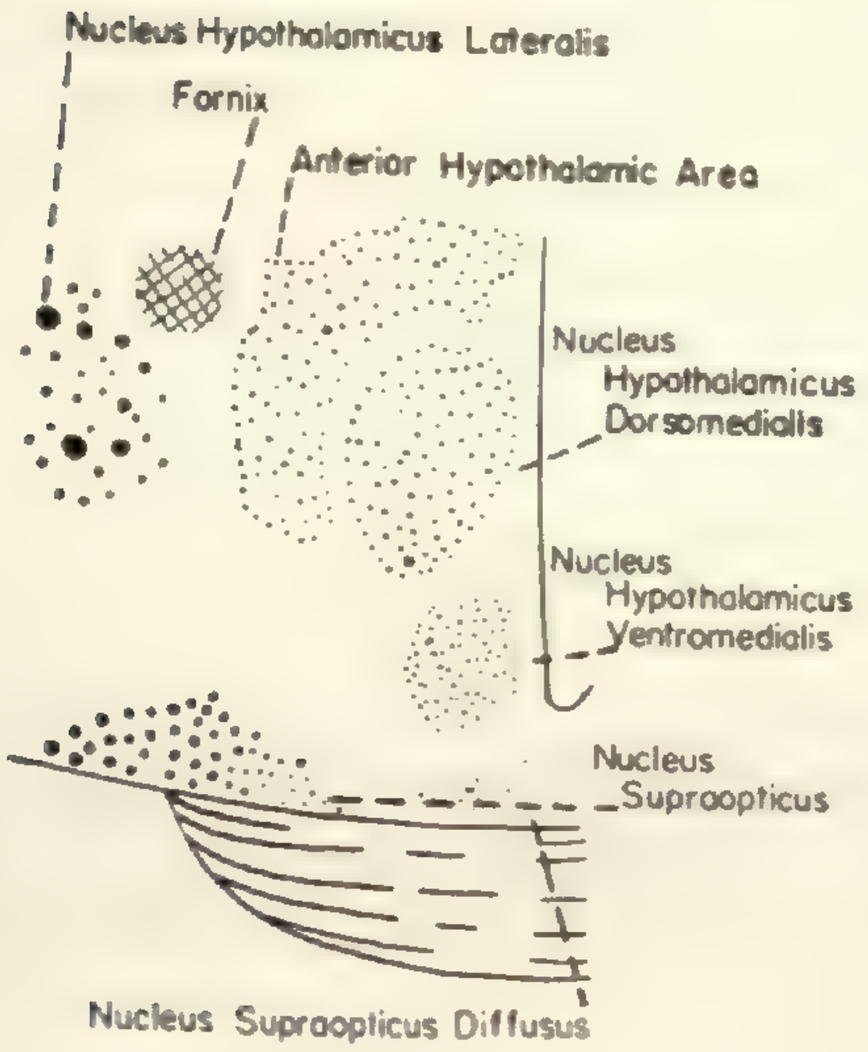
Anterior Hypothalamic Area: This group is located in the dorsal part of the anterior portion of the hypothalamus (Fig. 3

A). It is a poorly defined aggregate of small to medium-sized neurons. The medium-sized ones are central visceral efferent neurons and form the greater part of the nucleus. Among them are located small associational neurons.

Nucleus Hypothalamicus Ventrolateralis:. The nucleus hypothalamicus ventrolateralis lies medial and ventromedial to the anterior pillar of the fornix (Fig. 3 B). It is separated from the ventral margin of the hypothalamus by undifferentiated gray matter. The central somatic efferent neurons outnumber the associational neurons, which are uniformily distributed among them. Reports of known fiber connections are wanting. The cytological structure of the neurons suggests connections with neighboring hypothalamic nuclei through the associational neurons and with preganglionic neurons at lower levels in the brain stem through the central visceral efferent neurons.

Nucleus Mammillaris Medialis: This nucleus consists of a large dorsomedial and a smaller ventrolateral portion (Fig. 3 D). The former includes mainly central visceral efferent neurons; the latter associational neurons. This nucleus and the nucleus mammillaris lateralis form the mammillary body. All the neurons in the nucleus mammillaris medialis are poorly supplied with chromidia, especially those in the ventrolateral portion. The chromidia are finely granular and tend to have either an extreme peripheral or perinuclear distribution. In the latter case they form a rather complete, thin, dark ring. The fibers of the mammillo-thalamic and mammillo-tegmental tracts arise mainly in this nucleus. Gurdjian (1927) found that the commissural portion between the mammillary bodies contains cells whose processes connect the nuclei of the opposite sides.

Nucleus Supramammillaris: This nucleus is quite completely isolated, although the neurons are not compactly arranged. It is located along the dorsomedial margin of the cerebral peduncle in the extreme lateral portion of the hypothalamus. Central visceral efferent and associational neurons are uniformily



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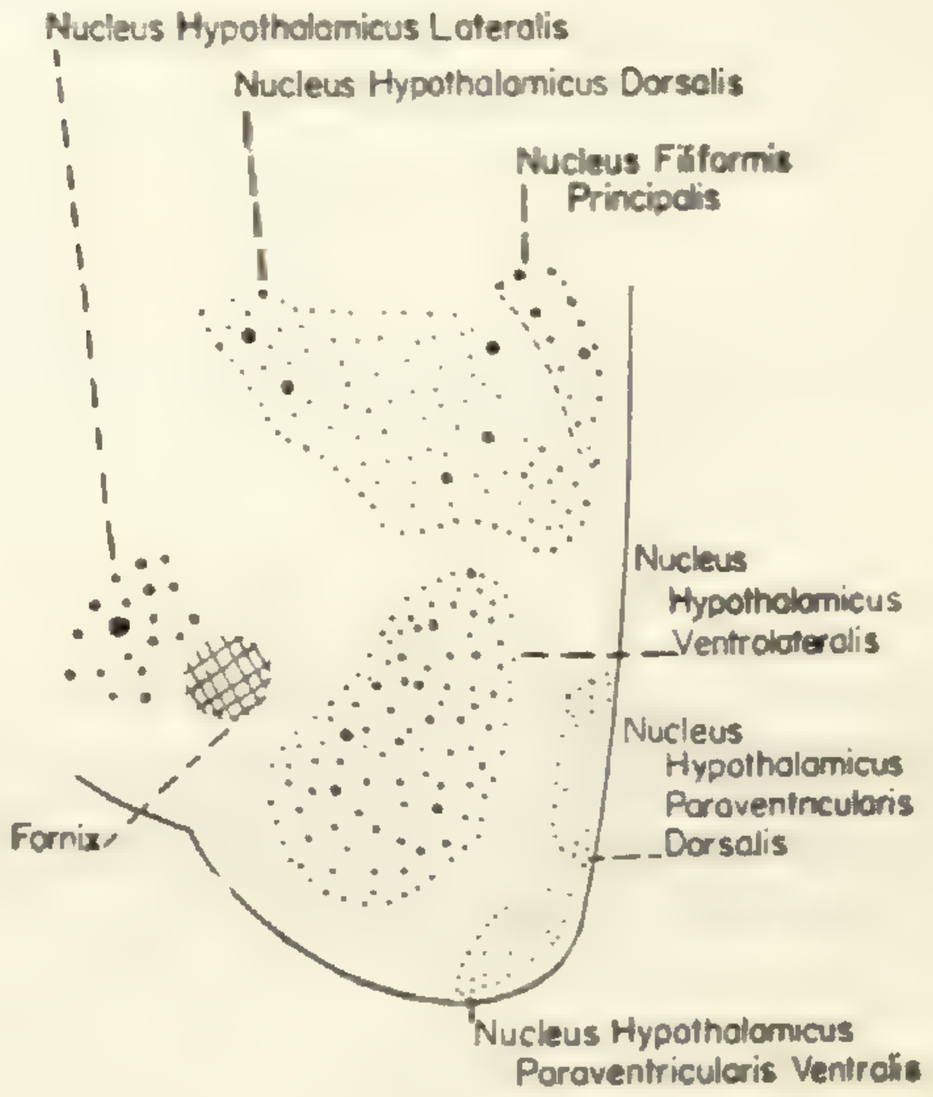

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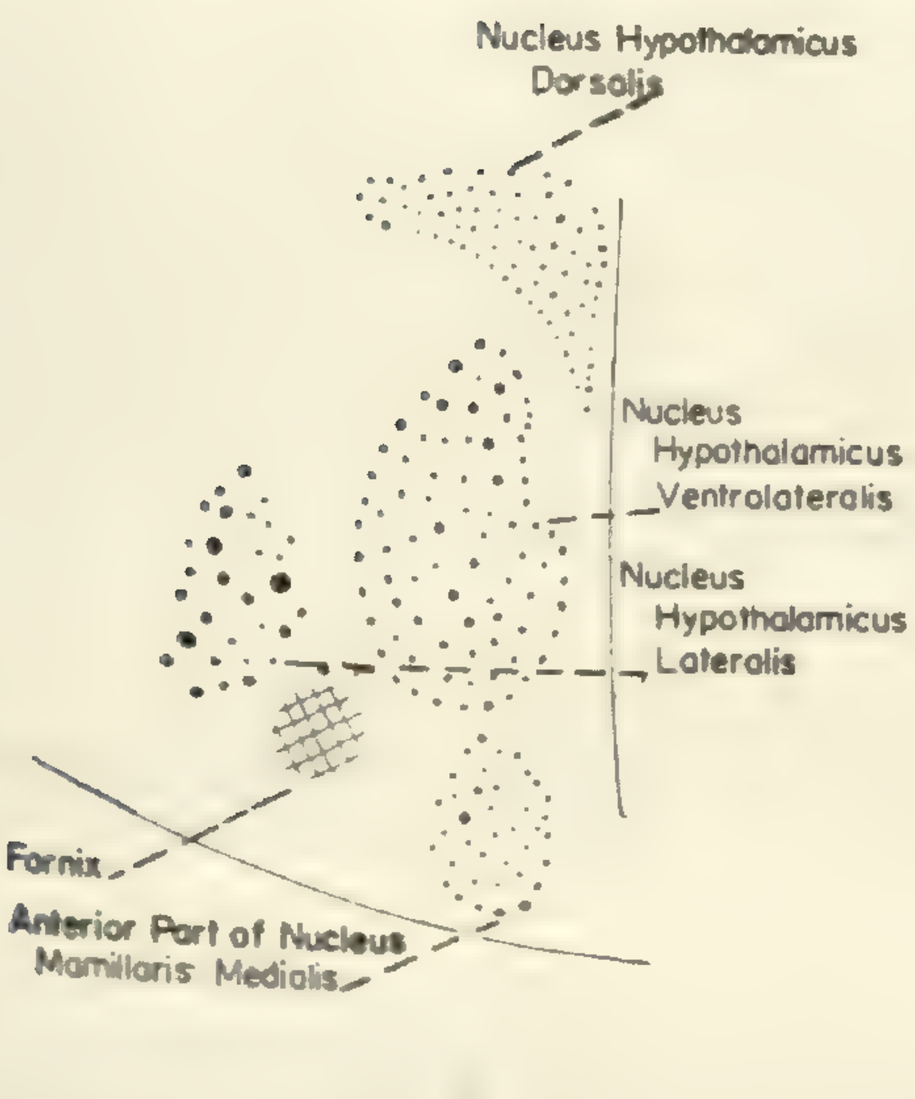

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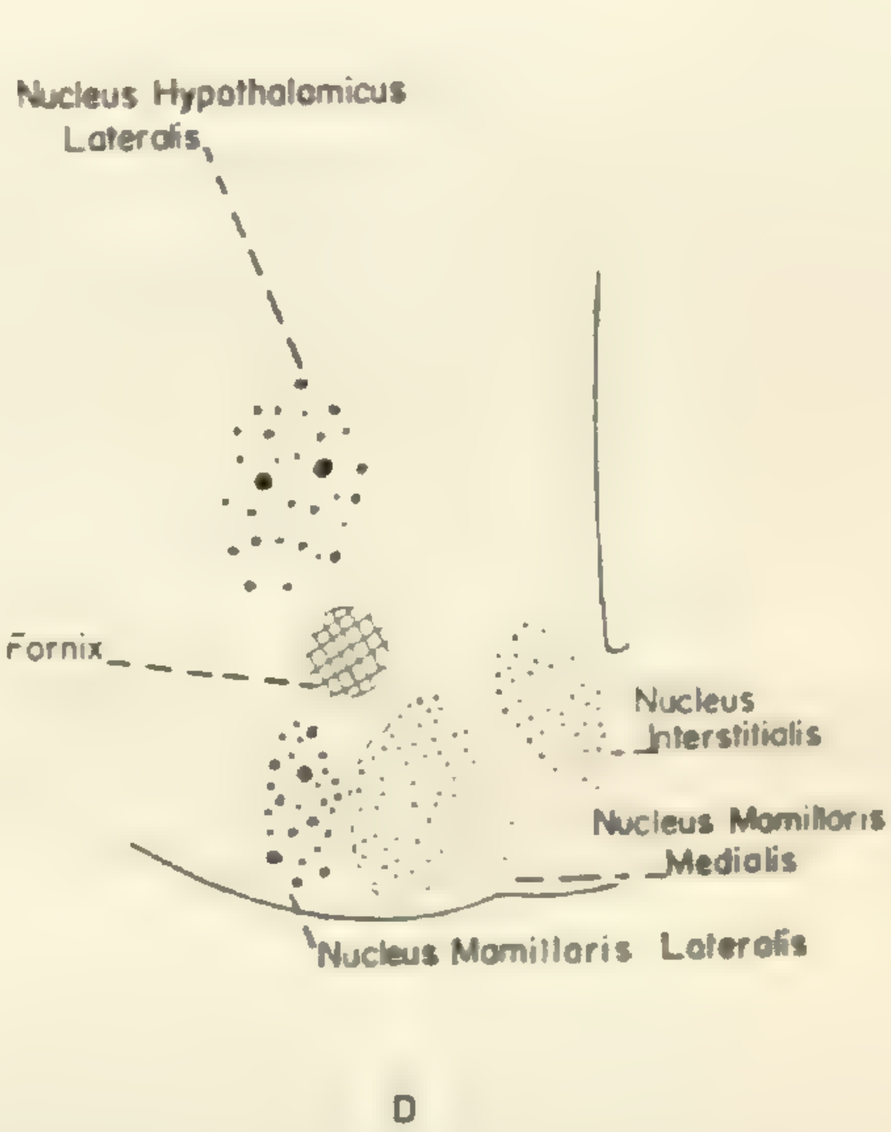

D

Figure 3. Sections of the hypothalamus showing the principal nuclei.

A, At level of the optic chiasm.
B, Through anterior portion of tuber cinereum.
C, Through posterior portion of tuber cinereum.
D, At level of mammillary bodies.

distributed throughout the nucleus. Definite fiber connections are unknown.

Hypothalamic nuclei composed of associational neurons

Nucleus Supraopticus Diffusus: The neurons of this nucleus lie among the fibers of the supraoptic commissure just dorsal to the optic chiasm (Fig. 3 A). They are small, associational neurons well supplied with chromidia and, consequently, appear very dark in toluidin blue and erythrosin preparations. In some neurons the chromidia are more densely aggregated at one side of the nucleus than in other parts of the cytoplasm, giving that portion of the cell an exceedingly dark appearance. Functional connections are unreported but they must be essentially local.

Nucleus Suprachiasmaticus: This nucleus is located immediately lateral to the ventral tip to the anterior portion of the the third ventricle. Its neurons are spherical to slightly pear-shaped and are among the smallest and least abundantly supplied with chromidial substance of all the neurons of the hypothalamus. In most cases, however, the chromidia are sufficiently abundant to fill almost completely the relatively narrow zone of cytoplasm which surrounds the centrally placed nucleus. Functional connections of these neurons have not been reported.

Nucleus Periformicalis: The neurons of this nucleus lie between the fibers of the descending column of the fornix and adjacent to them. They are not definitely separated from the neurons in the adjacent gray matter. They are all associational. The chromidia form a very thin, incomplete perinuclear or peripheral ring. Knowledge regarding their functional connections is lacking.

Nucleus Parvocellularis: This nucleus lies in the extreme dorsal portion of the hypothalamus, just dorsal to the nucleus filiformis lateralis. All of the neurons are associational. The

chromidia are relatively coarse and, in the majority of the cells, are aggregated in the perinuclear or the peripheral zone. The morphology and chromidial pattern of these neurons suggest local functional connections.

Nuclei Hypothalamicus Periventricularis Dorsalis and Ventralis: These nuclei are closely associated. The nucleus hypothalamicus periventricularis ventralis is located at the most ventral margin of the hypothalamus, immediately lateral to the third ventricle and dorsolateral to the cavity of the infundibular stalk. The nucleus hypothalamicus periventricularis dorsalis occupies a position just dorsal to the latter nucleus and is incompletely separated from it (Fig. 3 B). Both are made up of typical associational neurons. The chromidia commonly have a peripheral distribution, but in some cells they are aggregated in the perinuclear zone. According to Gurdjian (1927), these nuclei probably contribute fibers to the periventricular system, at least in their posterior portions.

Nucleus Interstitialis: This nucleus lies dorsal to the fibers of the supramammillary decussation and among them (Fig. 3 D). Although the neurons are predominately associational, a considerable number of central visceral efferent neurons are present. Data regarding the functional connections of this nucleus are wanting.

SUMMARY and CONCLUSIONS

The results of the present study support the assumption that the neurons in the hypothalamic nuclei can be classified in four categories according to their functional relationships. These have been designated peripheral visceral efferent, central somatic efferent, central visceral efferent, and associational.

Peripheral visceral efferent neurons are characterized by medium or large size, spherical or polyhedral shape, coarse chro-

midial granules aggregated in the peripheral zone, and chromidial dust occupying the remainder of the cytoplasm of the cell body. Central somatic efferent neurons are cytologically similar to peripheral somatic efferent neurons. Their chromidia are coarse and occur as discreet units which are fairly uniformly distributed throughout the cell body. Most of them are polyhedral but some are nearly spherical in form. The central visceral efferent neurons are, in general, medium-sized, spherical or polyhedral cells with chromidia which are somewhat more granular than those of the associational neurons. The chromidia ferquently are aggregated in the peripheral zone but sometimes occur clumped in certain portions of the cytoplasm. Associational neurons are characterized by relatively very small size, fusiform or spherical shape, and a perinuclear distribution of the chromidia.

The majority of the neurons in the hypothalamus of the cat are central visceral efferent; next in abundance are the associational neurons. In those nuclei which contain central somatic efferent neurons and in those in which the more specialized visceral efferent neurons occur, associational and central visceral efferent neurons also are present in considerable abundance.

In view of the diverse sources of the afferent fibers and the connections effected by the efferent fibers which recently have been described for the various hypothalamic nuclei, most of these nuclei must include central visceral efferent and associational neurons and some of them also central somatic efferent neurons. In view of the finding that certain neurons in the nucleus supraopticus give rise to fibers which end in functional relationship to secretory cells of the posterior lobe of the hypophysis, the distinctive cytological characters of these cells also can be correlated with those of other peripheral visceral efferent neurons.

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VOLUME XXX, NO. 4

THE AGRICULTURAL ECONOMY OF THE AMERICAN BOTTOMS

IN MADISON AND ST. CLAIR COUNTIES, ILLINOIS

By

MENDEL E. BRANOM, PH. D.

Professor of Geography
Harris Teachers College
St. Louis, Mo.

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PART I[1]

DISTRIBUTIVE RELATIONSHIPS OF THE AGRICULTURAL PATTERN

Orientation

The location and extent of the American Bottoms.—Between Alton and Prairie du Pont Creek a notable expansion of the flood plain of the Mississippi River is known as the American Bottoms[2] (Fig. 1). The adjoining bluffs of weak Pennsylvanian rocks, overlain with glacial and loessial deposits, attain a maximum height in excess of two hundred feet above the flood plain but have been weathered and mellowed to such an extent that in most places it is possible to walk without difficulty to their summits (Fig. 2). Moreover, the continuity of the bluffs is interrupted here and there by valleys with intermittent or perennial streams.

The northern terminus of the American Bottoms is marked by a bold escarpment of limestone between which and the river a semi-artificial strip of lowland is barely wide enough for one railroad and one highway (Fig. 3). The southern terminus of the American Bottoms is similarly marked by precipitous limestone bluffs (Fig. 4). Between these bluffs and the river the flood plain is less than four miles in width.

The area of the American Bottoms is slightly in excess of one hundred thousand acres, of which about two-thirds is located in Madison County and about one-third in St. Clair County, Illinois. The region has a maximum north-south extent of about twenty-four miles and a maximum east-west extent of about eleven miles.

Salient features of the American Bottoms.—The American Bottoms is a nearly level alluvial plain approximately one-sixth of which consists

---

[1]This article is an abridgment of a dissertation (213 manuscript pages) which includes 17 maps, 32 graphs, 7 tables, and 44 pictures. Part I is essentially the same as Chapter I in the complete dissertation.

[2]N. M. Fenneman, *Physiography of the St. Louis Area* (Urbana: University of Illinois, 1909), p. 73.

of swamps and shallow lakes. Nearly all the timber, which formerly covered a large proportion of the area, has been removed except in some of the swamps. The surface drainage, naturally dependent on shifting meandering channels, has been improved by the construction of artificial and semi-artificial channels. Levees have been constructed to protect much of the flood plain from overflows of the Mississippi River; natural channels have been improved and artificial channels have been constructed to facilitate the movement of upland waters across the flood plain.

The soil types include loams, clays, and sands. The loams, considered best from an agricultural standpoint, predominate.

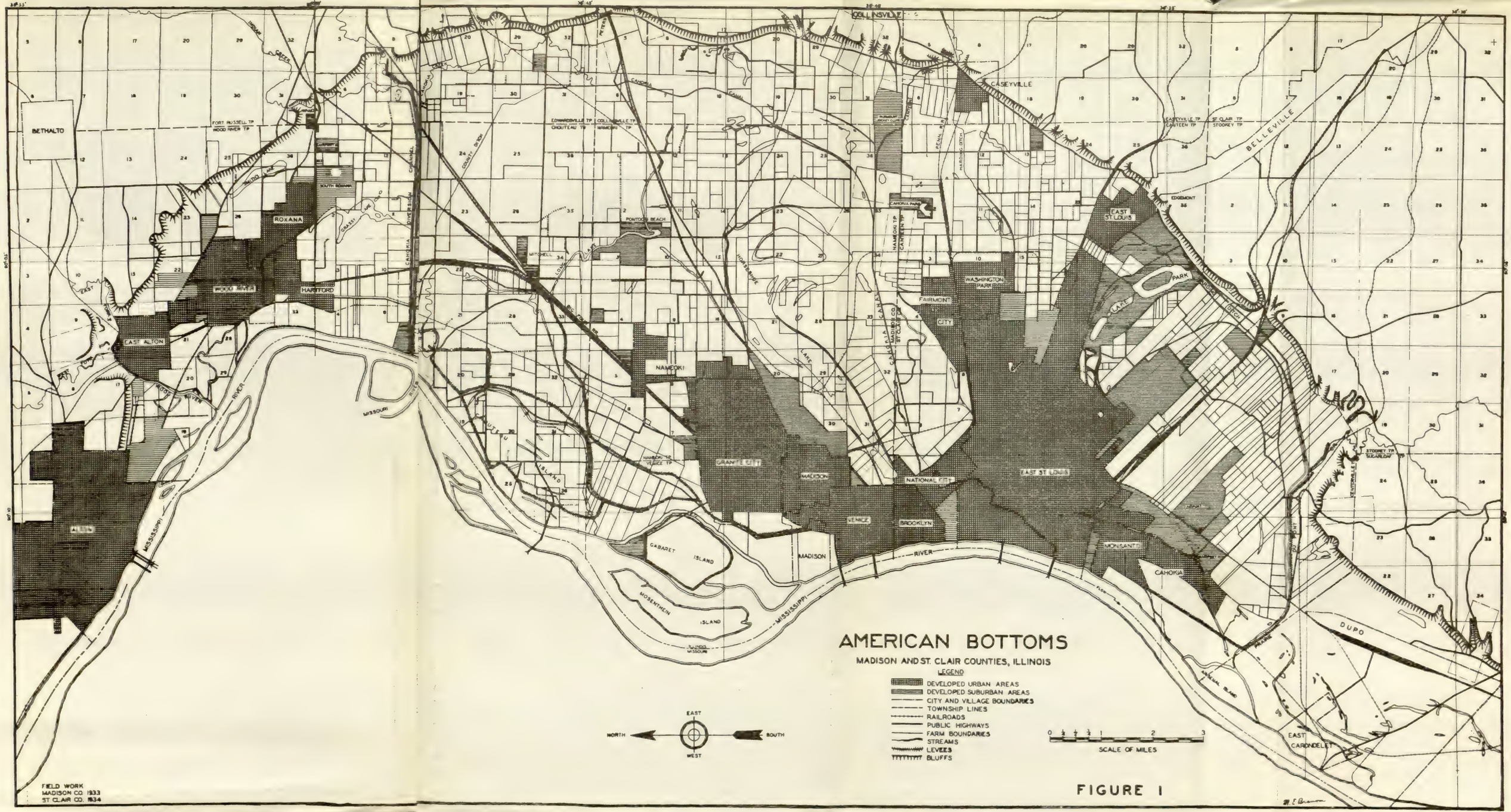
The salient features of the cultural pattern (Table 1) are: (a) twenty agricultural sections which comprise almost two-thirds of the total acreage; (b) two urban and suburban districts; (c) scattered small settlements including resort centers associated with lakes and streams; (d) railroads and highways, especially those which converge from breaks in the bluffs on the Southern Urban and Suburban District; and (e) extensive levee and drainage systems.[1]

TABLE 1

A CLASSIFICATION OF THE ACREAGE OF THE AMERICAN BOTTOMS

Classification	Acreage	Per Cent of Total Acreage
Agricultural sections	64,749.5	64.19
Southern Urban and Suburban District	22,640.0	22.44
Northern Urban and Suburban District	6,170.0	06.11
Swamps and water bodies not associated with operated farms	2,526.0	02.50
Resort centers and other small settlements	1,822.0	01.80
Rural railroad property and highways	1,520.0	01.50
Rural areas occupied by levees and drainage ditches	1,420.0	01.40
Total	100,847.5	99.94

[1]Throughout the dissertation, unless otherwise stated, statistical data are based on field work in Madison County in 1933 and in St. Clair County in 1934.



AMERICAN BOTTOMS

MADISON AND ST. CLAIR COUNTIES, ILLINOIS

LEGEND

- DEVELOPED URBAN AREAS
- DEVELOPED SUBURBAN AREAS
- CITY AND VILLAGE BOUNDARIES
- TOWNSHIP LINES
- RAILROADS
- PUBLIC HIGHWAYS
- FARM BOUNDARIES
- STREAMS
- LEVEES
- BLUFFS

FIELD WORK
MADISON CO. 1933
ST. CLAIR CO. 1934

FIGURE 1

FIG. 2—Characteristic mellow bluffs bordering the American Bottoms.

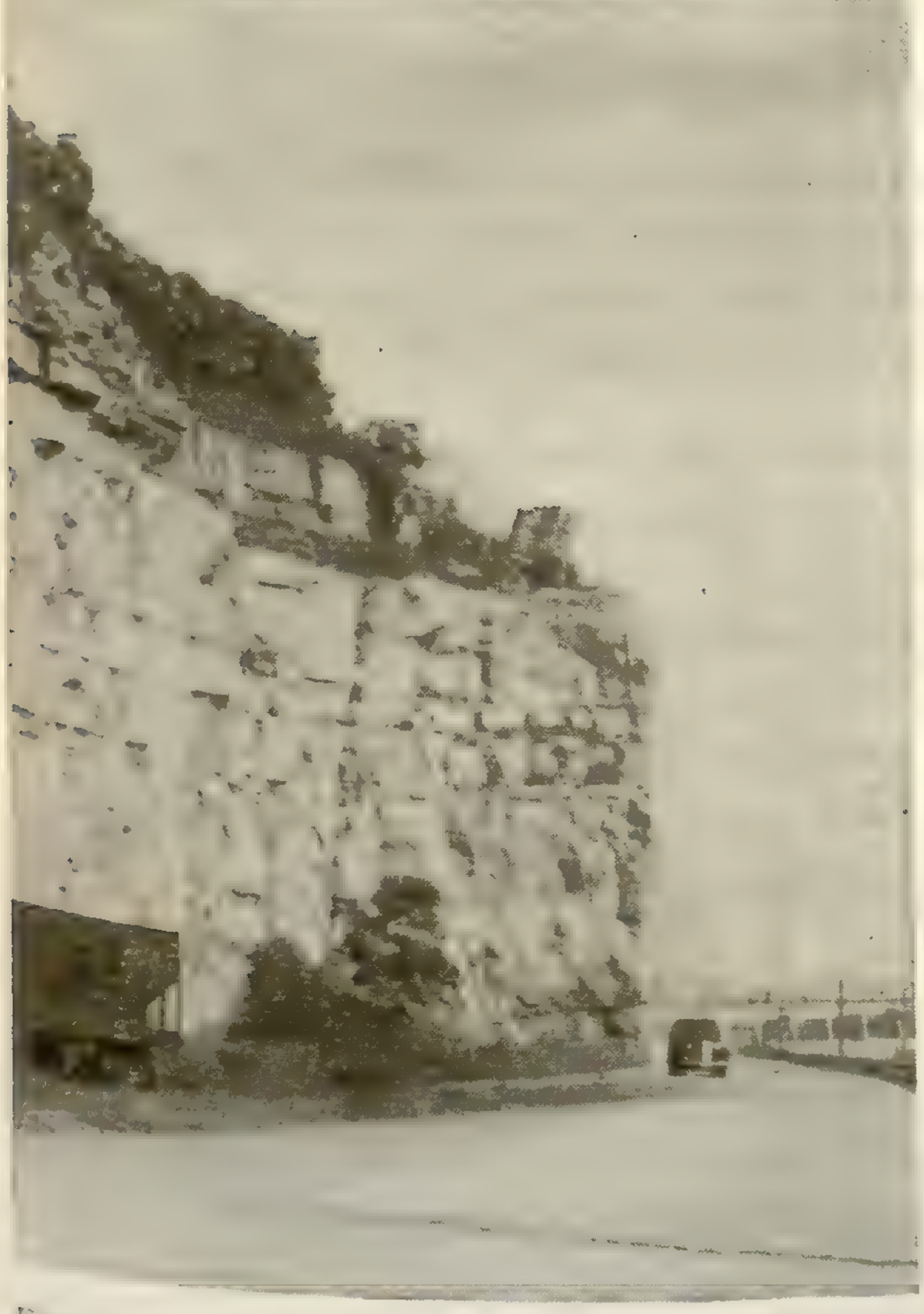


FIG. 3—Resistant limestone bluffs at the northern terminus of the American Bottoms.

FIG. 4—Resistant limestone bluffs at the southern terminus of the American Bottoms. A quarry has been opened at this place.

During most of the nineteenth century, the American Bottoms was noted chiefly for agricultural productivity. The only large concentration of population was in the East St. Louis area, on the opposite bank of the Mississippi River from St. Louis. Since 1896, however, when the Niedringhaus interests moved their enameling and stamping plant from St. Louis to the East Side and founded Granite City,[1] a notable expansion of the Southern Urban and Suburban District has taken place. A similarly rapid expansion of the Northern Urban and Suburban District began with the construction of an oil refinery near the mouth of Wood River in 1907.[2] In both districts the multiplication of industrial plants has been accompanied by the development of residential subdivisions.

The superimposition of transportation, urban, and suburban structures on the agricultural pattern of the American Bottoms has resulted in a complex, composite pattern of land utilization. As a consequence of urbanization, the agricultural pattern itself has undergone significant modifications.

The Composition of the Agricultural Pattern

General considerations.—The American Bottoms is included in an agricultural subdivision of Illinois known as the Southwestern Area (Fig. 5). Nearly two-thirds of the income from farming in this area is "derived from sales of wheat, dairy products, and poultry." [3]

Almost three-fourths of the farming area of the American Bottoms is in field crops (Fig. 6). More than half the remaining farm acreage is uncultivable because of lakes and swamps. The acreage of fallow land is more than half the acreage of lakes and swamps. Under "miscellanies," (Fig. 6), is included the combined proportions of acreage used for farmsteads, pastures, and wood lots. The figure suggests that the income of the farming population is derived chiefly from field crops and that a sizable proportion of the acreage is of slight agricultural importance.

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[1] Lewis F. Thomas, *The Localization of Business Activities in Metropolitan St. Louis* (St. Louis: Washington University, 1927) p. 88.

[2] *Alton Evening Telegraph*, Centennial Number, January, 1936.

[3] H. C. M. Case and K. H. Meyers, *Types of Farming in Illinois*, Bulletin 403 (Urbana: University of Illinois, 1934), p. 182.

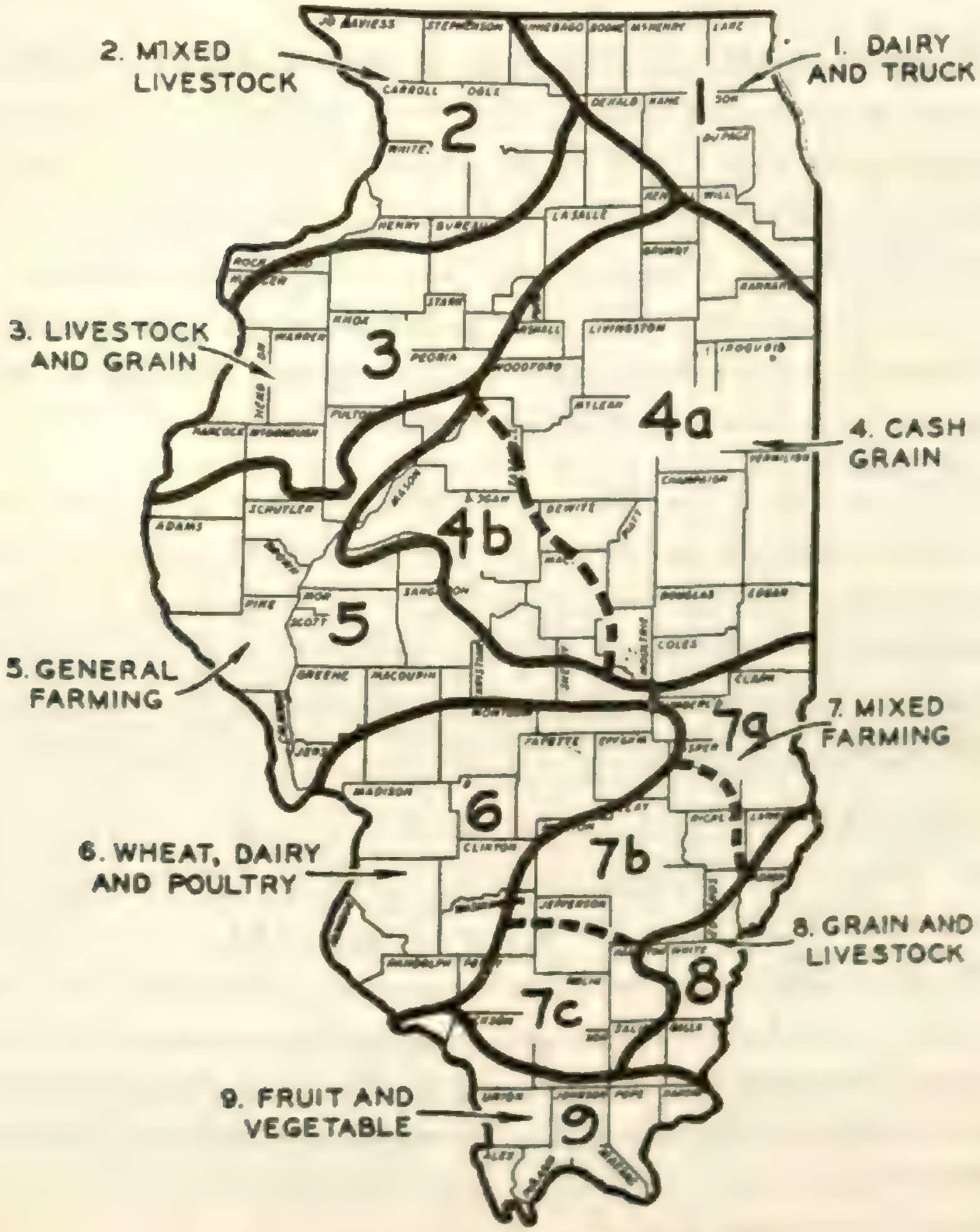

FIG. 5—Types of farming in Illinois.

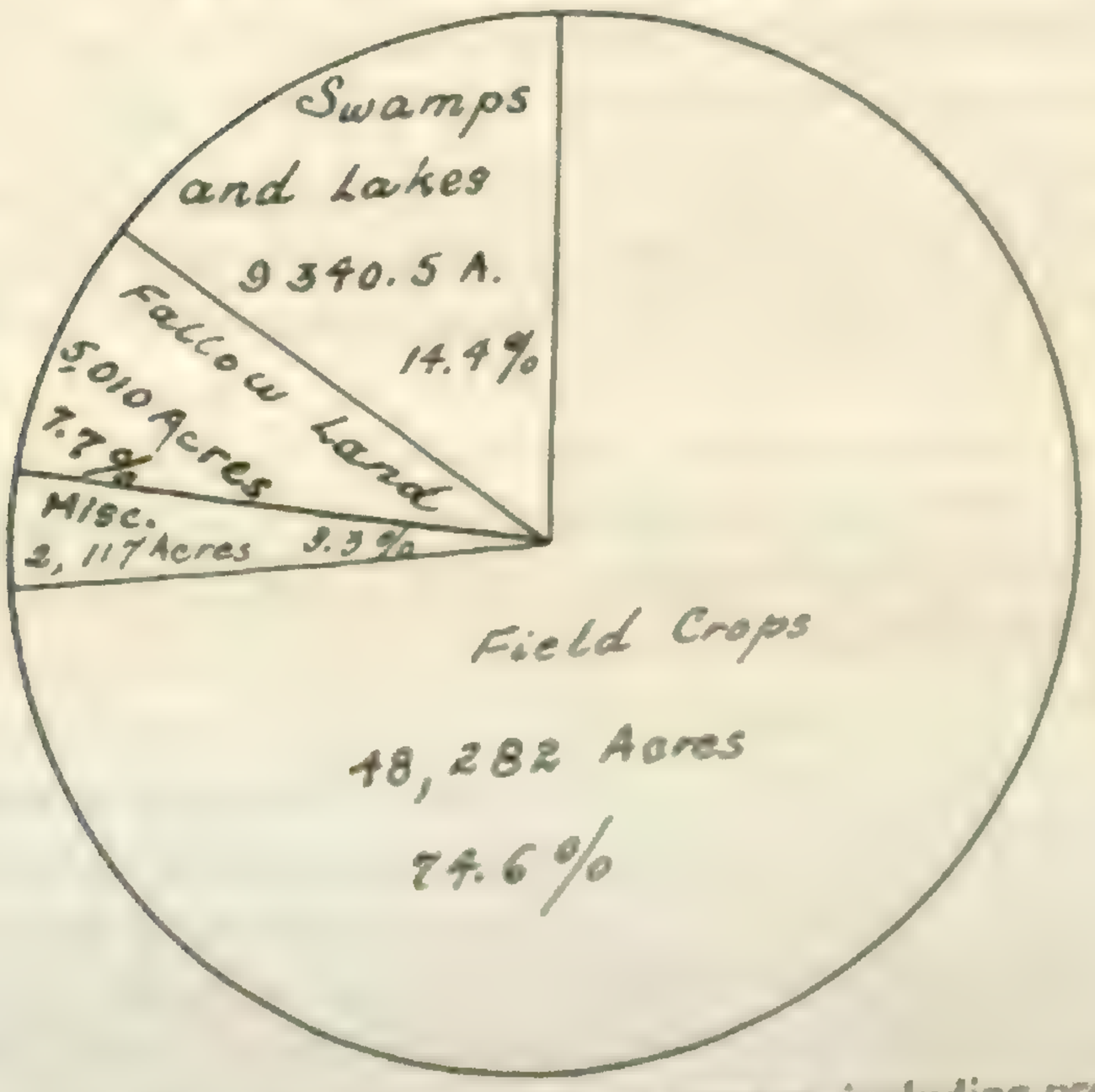

FIG. 6—A proportional classification of farm acreage, including productive and non-productive acreage.

The 781 farms which comprise the agricultural area of the American Bottoms have an average acreage of 82.9, which is substantially lower than the average of 127 for the Southwestern Area.[1] More than two-fifths of the farms have an area of forty acres or less; more than nine-tenths have an area of 160 acres or less (Fig. 7). However, the farms which do not exceed forty acres include only 12.5 per cent of the total acreage in farms; the farms which do not exceed 160 acres include only 65.5 per cent of the total acreage in farms (Fig. 8).

It is significant that the 781 ownership farms[2] are operated by only 578 farmers who control an average acreage of 112.02. Of the farmers, 31.9 per cent operate forty acres or less; 57.3 per cent operate eighty acres or less; and 81.3 per cent operate 160 acres or less (Fig. 9). Many of the farmers operate on a relatively small scale, but some operate on a relatively large scale.

Almost two-thirds of the farms of the American Bottoms have improvements (Fig. 10). Farms with an acreage of 160 or less account for 88.1 per cent of all sets of improvements (Fig. 11). Only 62.9 per cent of all such farms have improvements, however, in contrast to 96.8 per cent of all farms with an acreage in excess of 160. Although the American Bottoms has 578 farmers, there are only 513 sets of improvements. Most of the sixty-five farmers who do not live on the land they cultivate are truck gardeners who live in cities or villages, or on other farms with relatives.

Farms with improvements have an average acreage of 99.31. Many of them are too small, considering the type of agricultural economy practiced, to permit an economical use of modern labor-saving machinery. Consequently an active demand exists for rentable farms. Although it is not unusual for a farmer to cultivate a parcel of land located some distance from the farm on which he lives, most rented land is operated by farmers on contiguous farms. Most of the farmers who care for forty acres or less are truck gardeners who have an ample acreage considering the intensive farming methods used. If this group of farmers is omitted, the remaining 394 farmers, practically all of whom live on farms which they operate, have an average acreage of 154.05. A combination of ownership farms for farming purposes provides for many farmers living on relatively small ownership farms an acreage which is considered ample

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[1] *Ibid*, p. 181.

[2] A continuous tract of land treated by the owner as a unit.

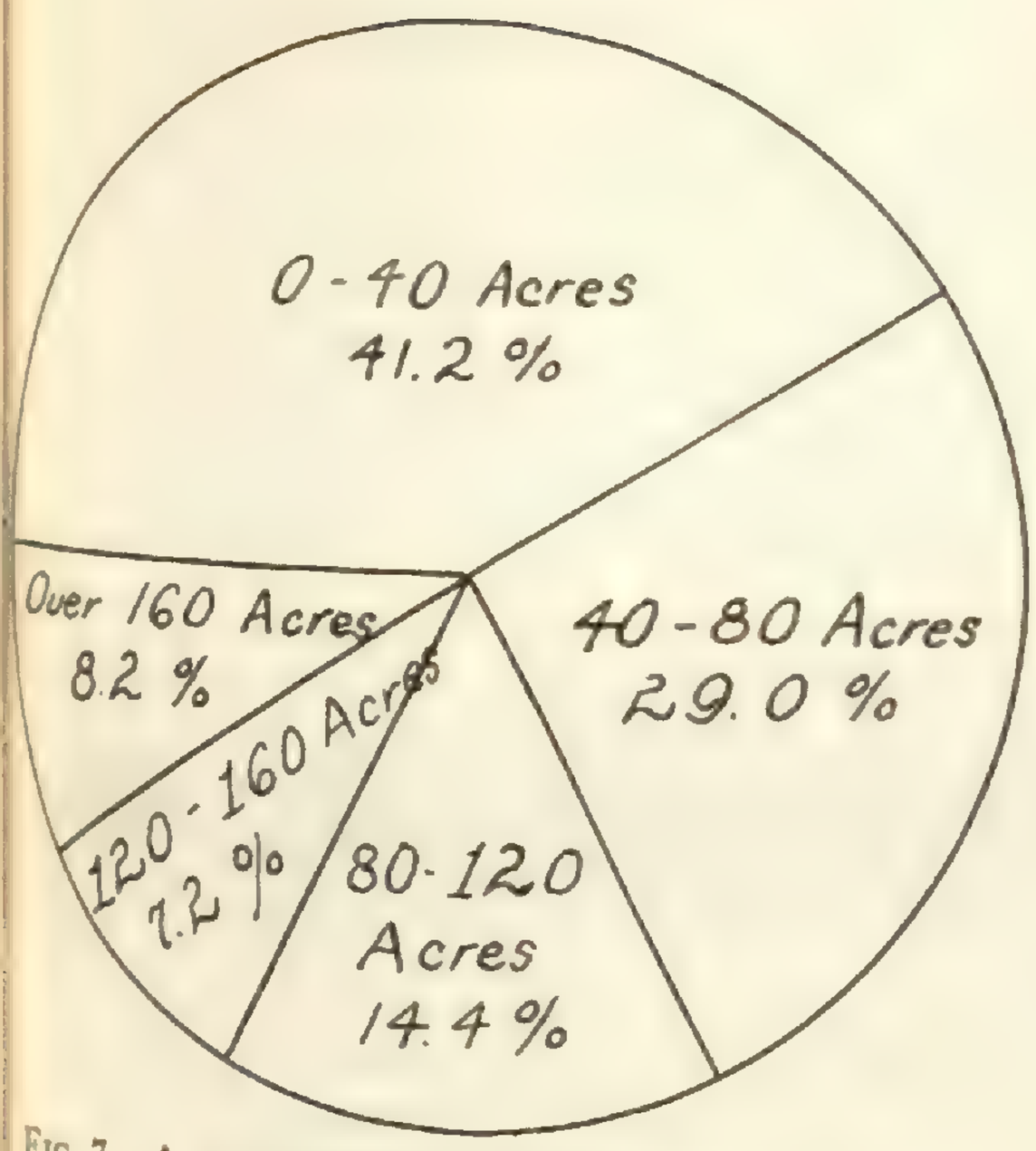

FIG. 7—A proportional classification of farms by acreage range.

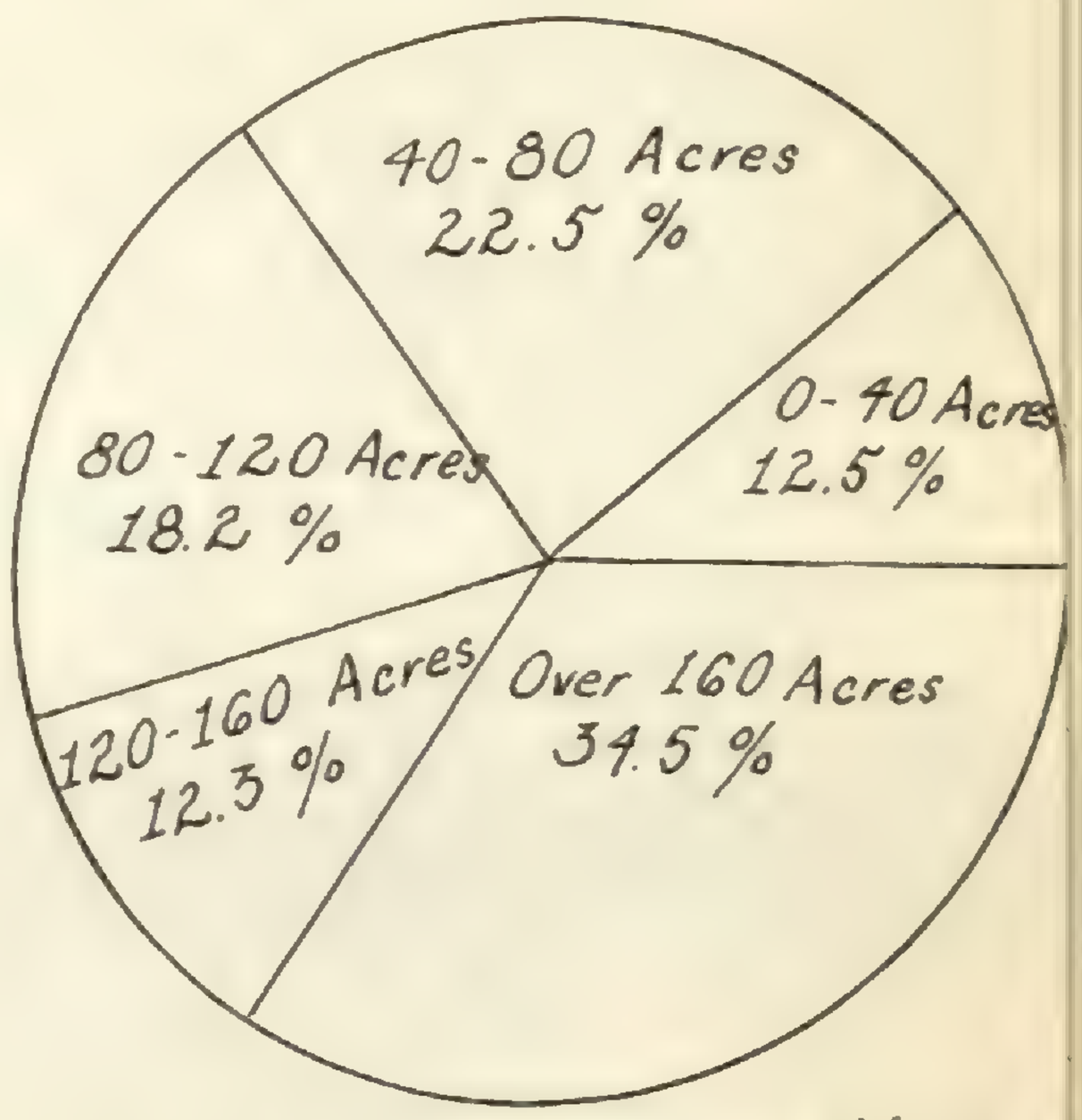

FIG. 8—The combined acreage of farms grouped by acreage range of farms.

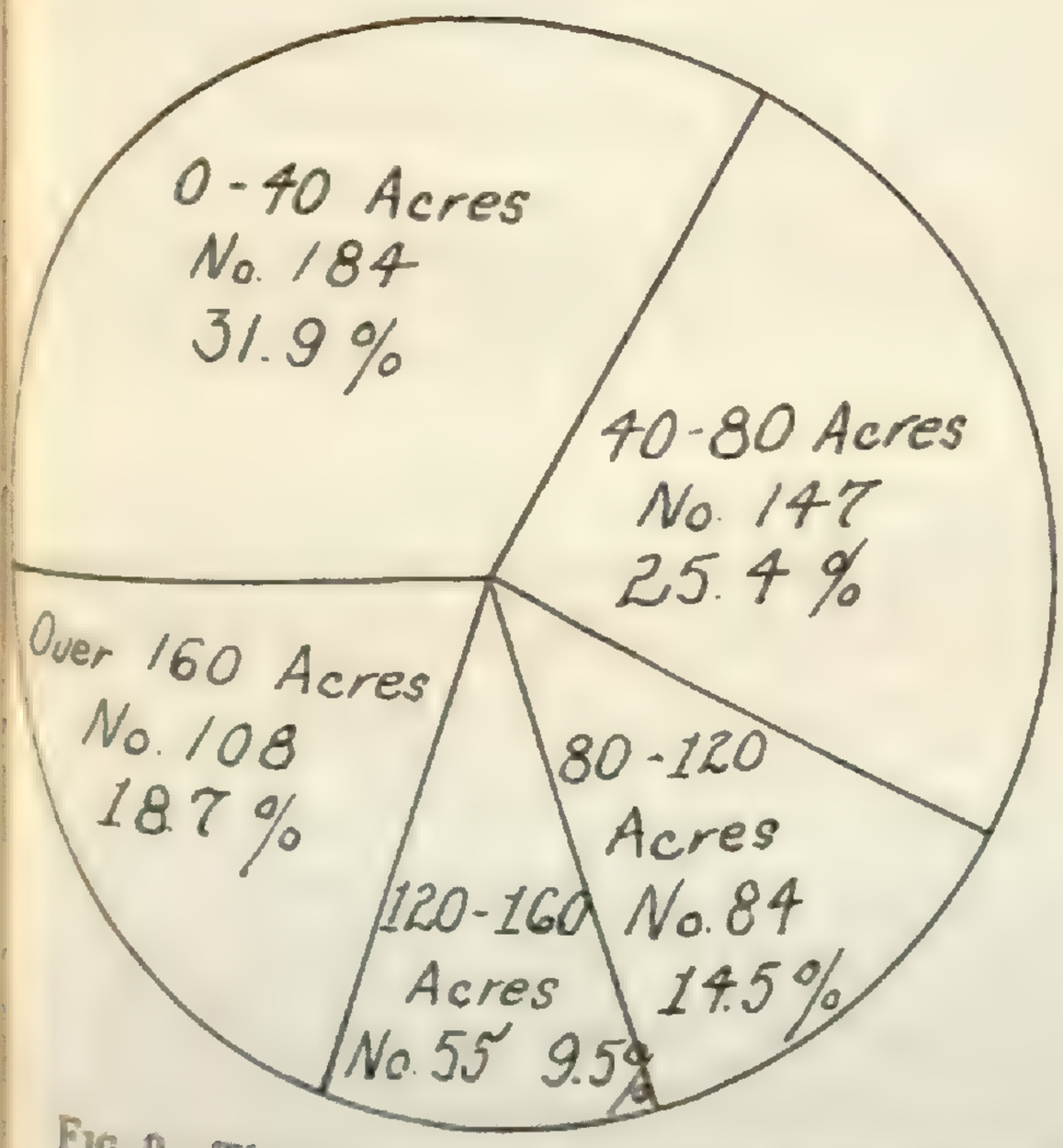

FIG. 9—The proportion of farmers according to the acreage range of land farmed.

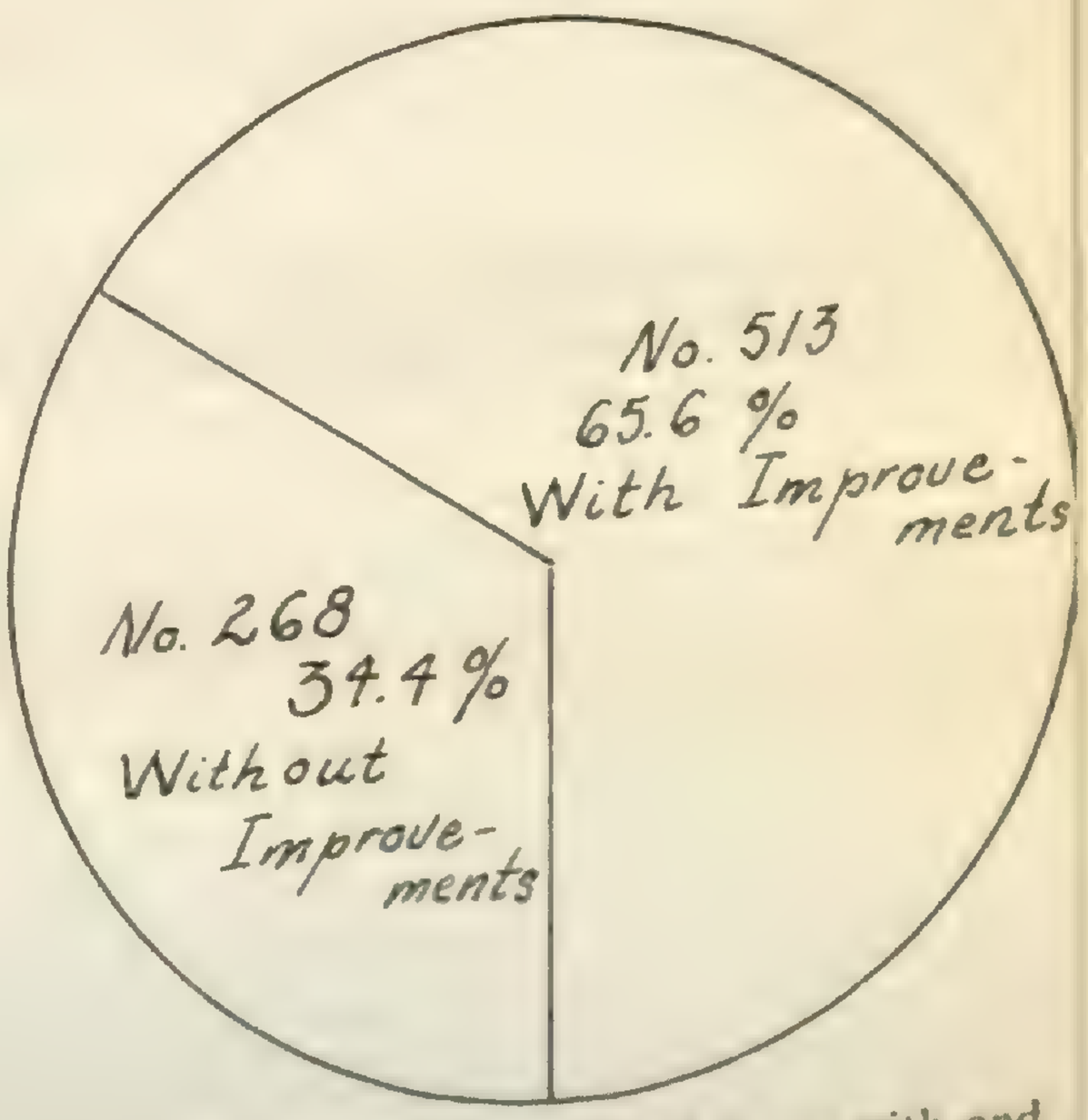

FIG. 10—The proportion of farms with and without improvements.

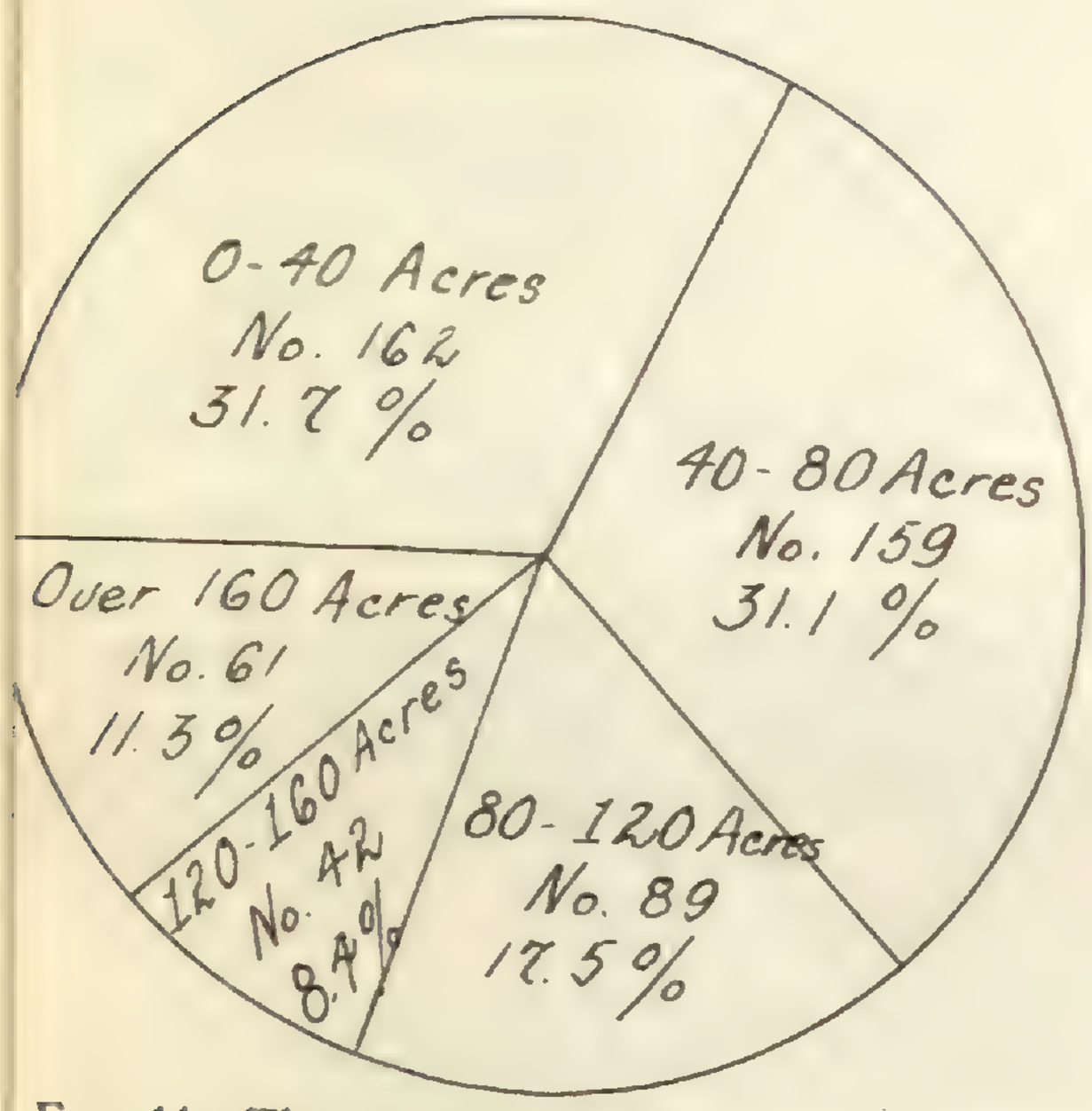

FIG. 11—The proportion of farms with improvements by acreage range of farms.

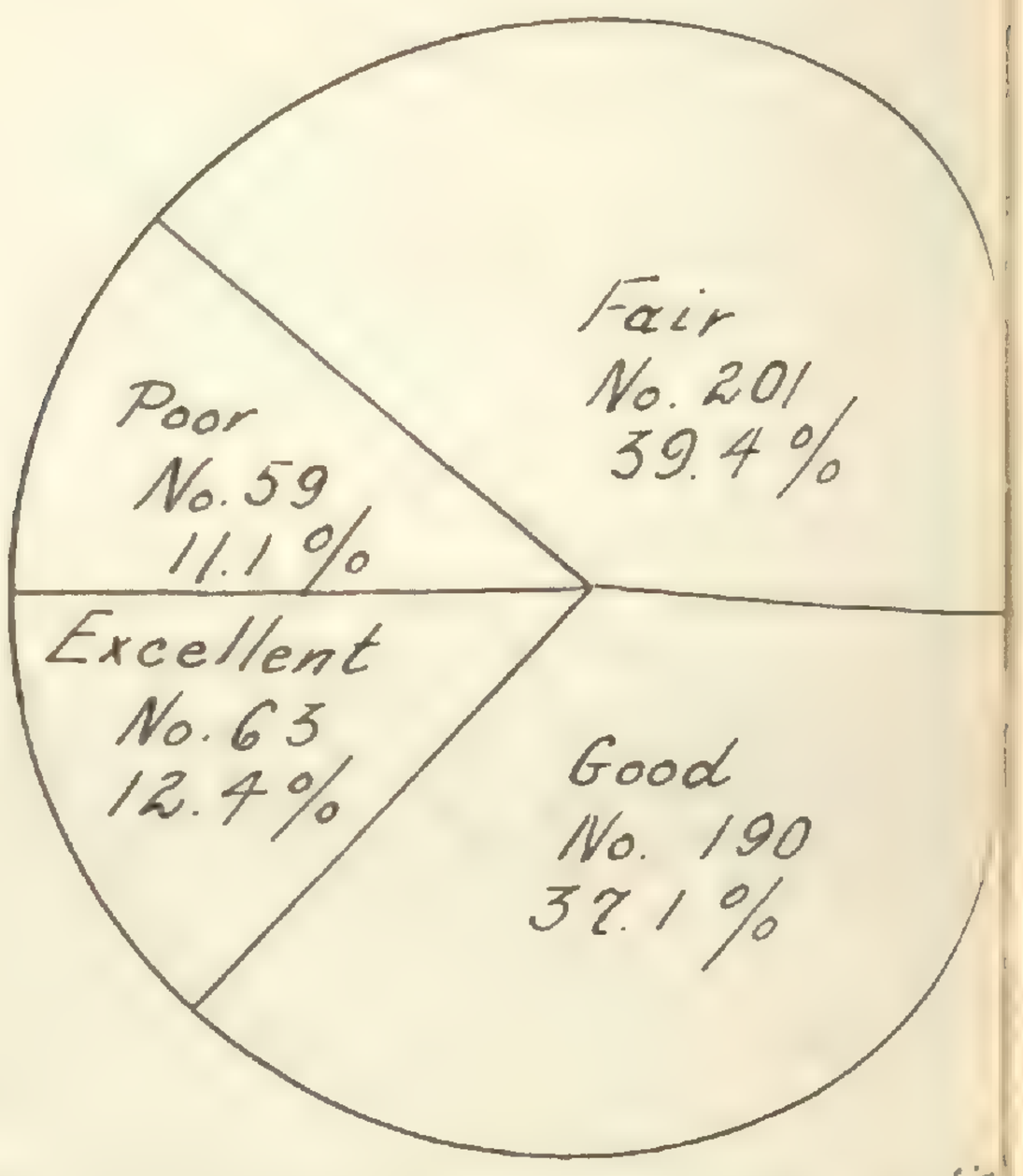

FIG. 12—A proportional classification of improvements as to condition.

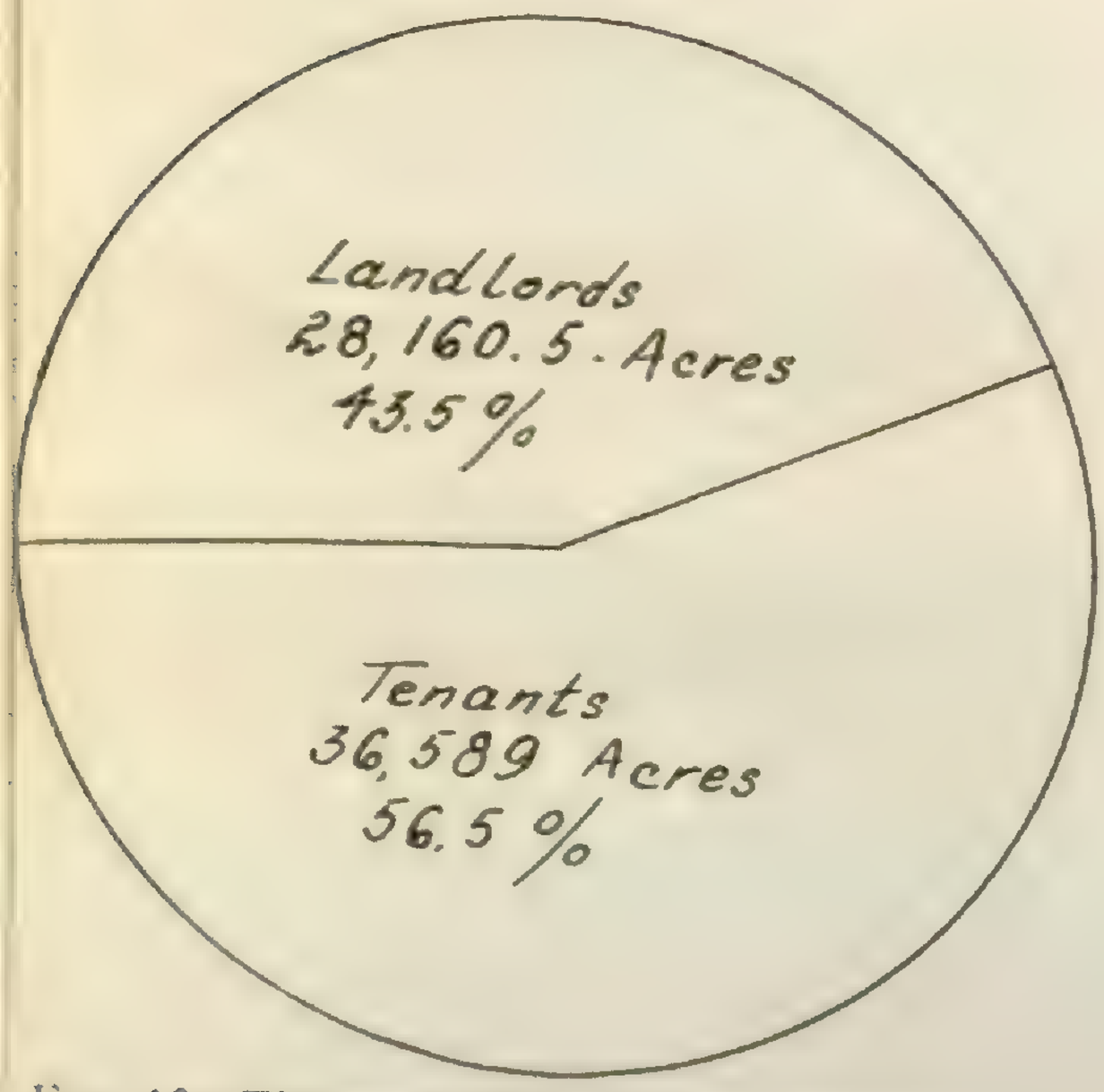

FIG. 13—The proportion of land farmed by tenants and by landlords.

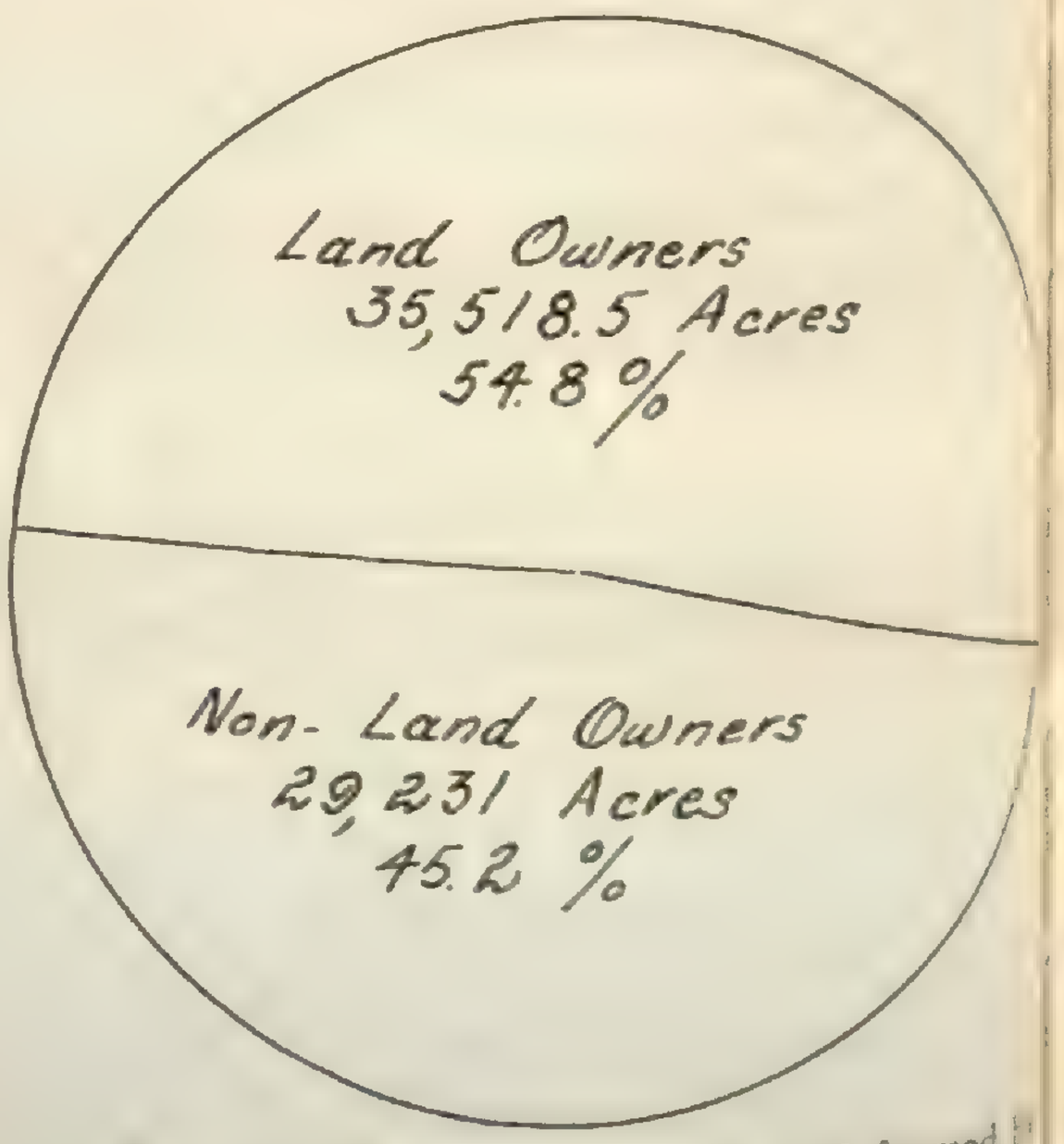

FIG. 14—The proportion of land farmed by land owners and non-land owners.

to warrant the use of the best labor-saving machinery even though the financial outlay is heavy.

The farm improvements as a group are suggestive neither of general poverty nor of marked prosperity (Fig. 12). Over three-fourths of the sets of improvements are either good or fair. The number of farms with fair sets of improvements is but slightly in excess of the number with good sets. The number of farms with excellent sets exceeds but slightly the number with poor sets. The sets of improvements on sixteen of the largest seventeen farms are only fair.

Almost three-fifths of the total farm acreage is operated by tenants (Fig 13). The highest incidence between tenancy and acreage exists among farms exceeding 320 acres, where tenants are in charge of more than ninety per cent of the 19,033 acres represented. Only 43.49 per cent of the total farm acreage is owned and operated by landlords. However, these land owners actually operate 54.82 per cent of the total farm acreage (Fig. 14). The supplementary acreage rented by land owners provides an average increase of more than twenty-five per cent in the amount of land farmed. At present, 68.33 per cent of all farmers of the American Bottoms are land owners (Fig. 15). Over half the land owners who cultivate their own farms have holdings which are eighty acres or less in extent (Fig. 16). Only 4.1 per cent of the land owners who operate their own farms have farms larger than 240 acres.

A few large tenant farms tend to obscure the fact than over two-fifths of the land is farmed by owners; that over half the land is farmed by individuals who own land in the American Bottoms; and that over two-thirds of the farmers are land owners.

The crop pattern.—Wheat and corn are the most important crops by acreage. They embrace over three-fourths of the field crop acreage (Table 2). Twenty-one other kinds of field crops are represented, but none of these crops accounts for as much as six per cent of the total field crop acreage. Wheat, corn, potatoes, sweet corn, and horseradish occupy more than ninety per cent of all the acreage in field crops.

Although wheat and corn are outstanding crops for the American Bottoms as a whole, their relative importance is not everywhere the same. In some places crops of minor rank for the American Bottoms as a whole increase materially in acreage and even become more important than either wheat or corn. On the basis of acreage variations in the relative emphasis placed on the different kinds of field crops, nine different types of agricultural economy have been identified (Table 3). Two of the types are differentiated also on the basis of animal husbandry.

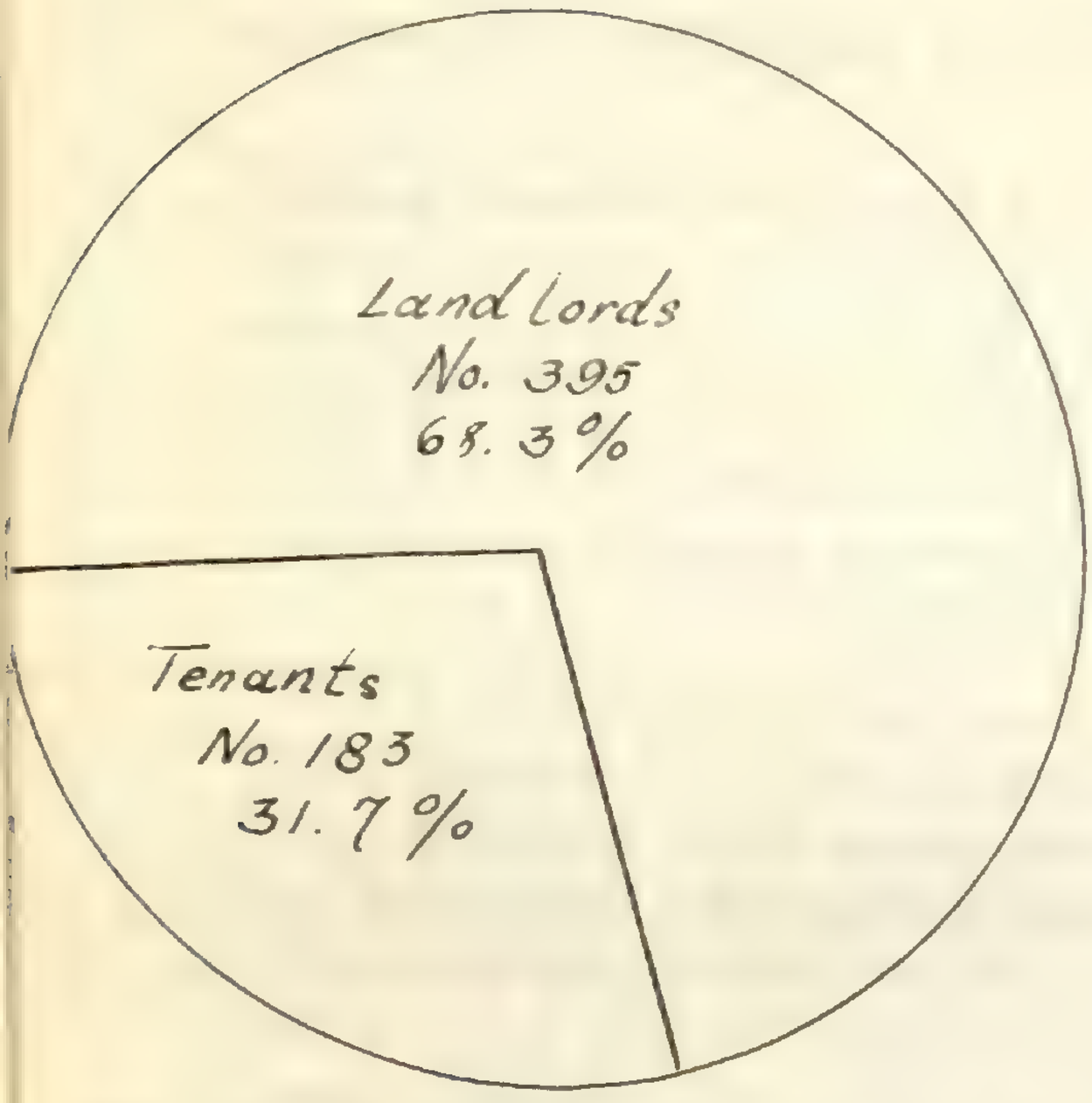

FIG. 15—The proportion of landlords and tenants.

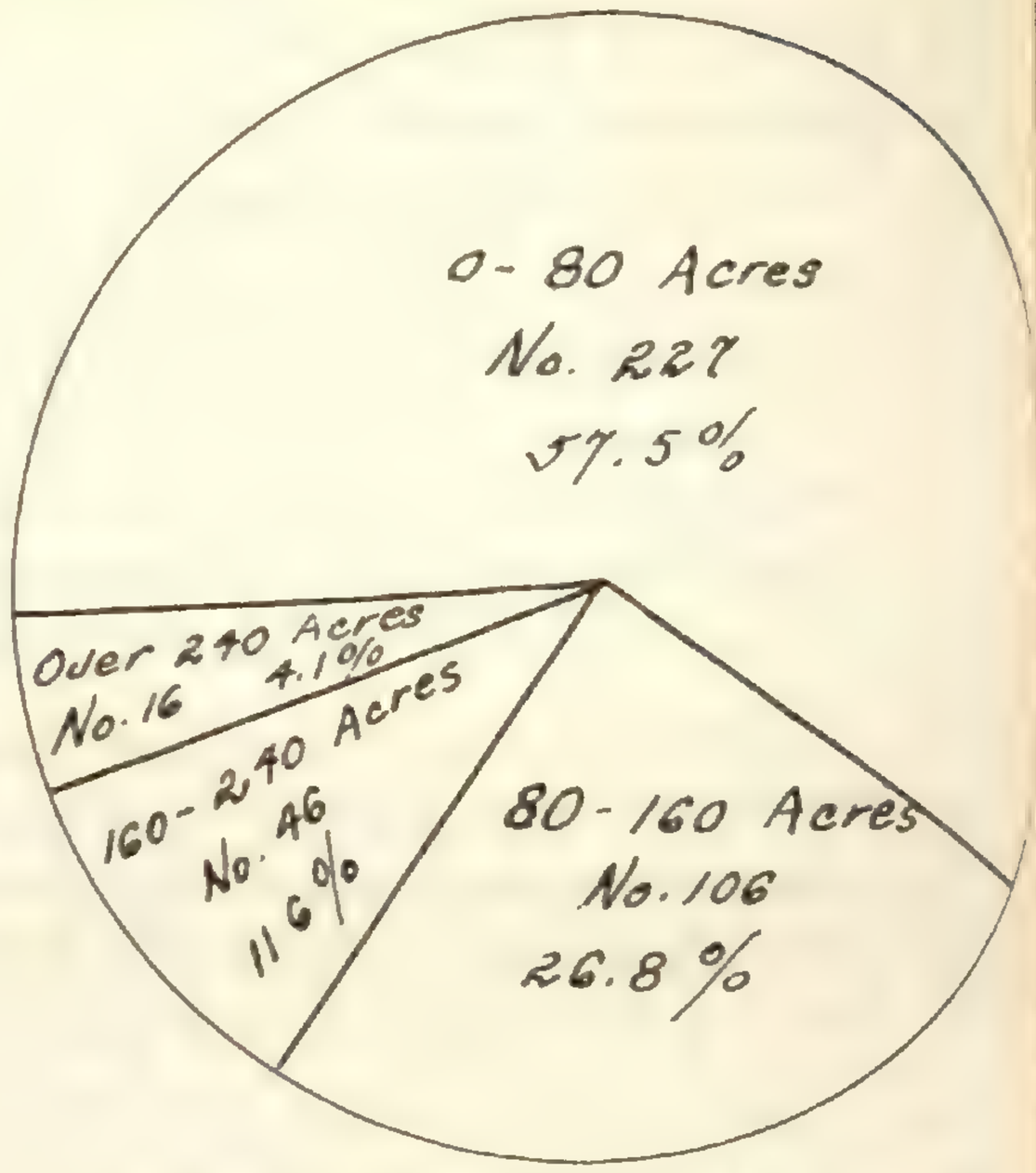

FIG. 16—The proportion of landlords by acreage range.

TABLE 2

THE RELATIVE IMPORTANCE OF FIELD CROPS BY ACREAGE

Field Crops	Acreage	Per Cent of All Field Crops	Per Cent of Farmlands
Wheat	21,797.00	45.16	33.66
Horse Corn	15,591.00	32.49	24.22
Potatoes	2,591.00	05.36	04.00
Sweet Corn	2,151.50	04.45	03.32
Horseradish	1,776.50	03.67	02.74
Cantaloupes	735.00	01.52	01.13
Rye	731.00	01.51	01.12
Alfalfa	679.50	01.40	01.04
Oats	618.00	01.27	00.95
Cabbage	475.50	00.98	00.73
Tomatoes	292.50	00.60	00.45
Soy Beans	213.00	00.44	00.32
Red Clover	210.00	00.43	00.32
Timothy	83.00	00.17	00.12
Cucumbers	49.75	00.10	00.07
Pop Corn	47.50	00.09	00.07
Truck (Misc.)	40.50	00.08	00.06
Sweet Potatoes	35.00	00.07	00.05
Lespedeza	33.00	00.06	00.05
Fruits	17.00	00.03	00.02
Watermelons	12.50	00.02	00.01
Asparagus	4.00	00.00	00.00
Green Beans	2.75	00.00	00.00
Total	48,282.50	99.90	74.43

TABLE 3

THE ACREAGE REPRESENTING THE DIFFERENT TYPES OF AGRICULTURAL ECONOMY

Types of Agricultural Economy	Acreage	Per Cent of Total
Wheat-corn economy with significant minor crops.	16,391.0	25.31
Wheat-corn economy	16,022.0	24.74
Corn-wheat economy	10,862.0	16.74
Truck economy	6,084.5	09.39
Diversified products-livestock economy	4,429.0	06.84
Grain-dairy products economy	3,428.0	05.29
Grain-horseradish economy	3,351.0	05.17
Grain-potato economy	3,162.0	04.88
Cantaloupe-grain economy	1,020.0	01.57
Total	64,749.5	99.93

Except in the section with a grain-dairy products economy and the section with a diversified products-livestock economy, livestock are maintained on farms chiefly to supply family needs. In the two sections mentioned, a significant proportion of the family income is derived from the sale of animals and animal products.

The American Bottoms includes seven sections[1] with a wheat-corn economy, four sections with a wheat-corn economy with significant minor crops, two sections with a corn-wheat economy, and two sections with a truck economy (Fig. 17). Each of the other five types of agricultural economy is represented by only one section. The sections including (a) the wheat-corn type with significant minor crops, (b) the wheat-corn type, and (c) the corn-wheat type comprise over two-thirds of the total farm acreage. The sections representing the various types of agricultural economy show a marked differentiation in the relative importance of various kinds of field crops (Table 4).

[1]A section is a group of contiguous farms with the same type of agricultural economy.

TABLE 4*

THE RELATIVE IMPORTANCE OF FIELD CROPS FOR THE SECTIONS REPRESENTING EACH TYPE OF AGRICULTURAL ECONOMY

Kinds of Field Crops	Types of Agricultural Economy								
	A Wheat-Corn Economy with Significant Minor Crops	A Wheat-Corn Economy	A Corn-Wheat Economy	A Truck Economy	A Diversified Products-Live-stock Economy	A Grain-Dairy Products Economy	A Grain-Horseradish Economy	A Grain-Potato Economy	A Cantaloupe-Grain Economy
	%	%	%	%	%	%	%	%	%
Wheat	55.07	73.49	24.02	12.64	37.90	49.60	13.20	18.00	11.54
Horse Corn	23.77	23.86	73.85	20.79	29.86	42.79	37.72	31.82	11.69
White Potatoes	7.32	0.32	0.12	11.31	1.89	.....	2.92	42.55	0.09
Sweet Corn	5.05	0.33	.....	26.96	0.39	.....	5.04	1.75	.....
Horseradish	2.96	.....	.....	9.09	.....	.....	37.36	3.72	.....
Cantaloupes	.....	0.04	.....	.....	4.51	.....	.....	.....	55.20
Rye	0.18	0.06	.....	.....	13.43	.....	.....	.....	18.48
Alfalfa	2.36	0.38	0.16	1.10	3.16	5.53	0.12	0.14	.....
Oats	1.76	0.66	1.53	0.14	3.59	.....	1.70	0.81	.....
Cabbage	0.11	.....	.....	9.57	.....	.....	0.44	.....	.....
Tomatoes	0.04	0.08	.....	5.28	0.31	.....	0.29	0.45	.....
Soy Beans	0.17	0.24	0.24	0.59	2.57	.....	0.55	0.23	.....
Red Clover	0.56	0.11	.....	0.38	1.10	2.06	0.08	0.52	.....
Timothy	0.08	0.14	.....	0.21	0.86	.....	0.42	.....	.....
Cucumbers	.....	.....	.....	1.01	.....	.....	0.08	.....	.....
Pop Corn	0.29	.....	.....	.....	.....	.....	.....	.....	0.74
Truck (Miscellaneous)	.....	0.14	0.06	.....	0.35	.....	.....	.....	0.59
Sweet Potatoes	0.04	.....	.....	0.61	.....	.....	.....	.....	.....
Lespedeza	0.14	.....	.....	.....	.....	.....	.....	.....	.....
Fruits	.....	0.07	.....	0.17	.....	.....	.....	.....	.....
Watermelons	.....	.....	.....	.....	.....	.....	.....	.....	1.23
Asparagus	.....	.....	.....	.....	.....	.....	.....	.....	0.39
Green Beans	.....	.....	.....	0.05	.....	.....	.....	.....	.....

*The per cents refer to the total field crop acreage and have been calculated only through hundredths.

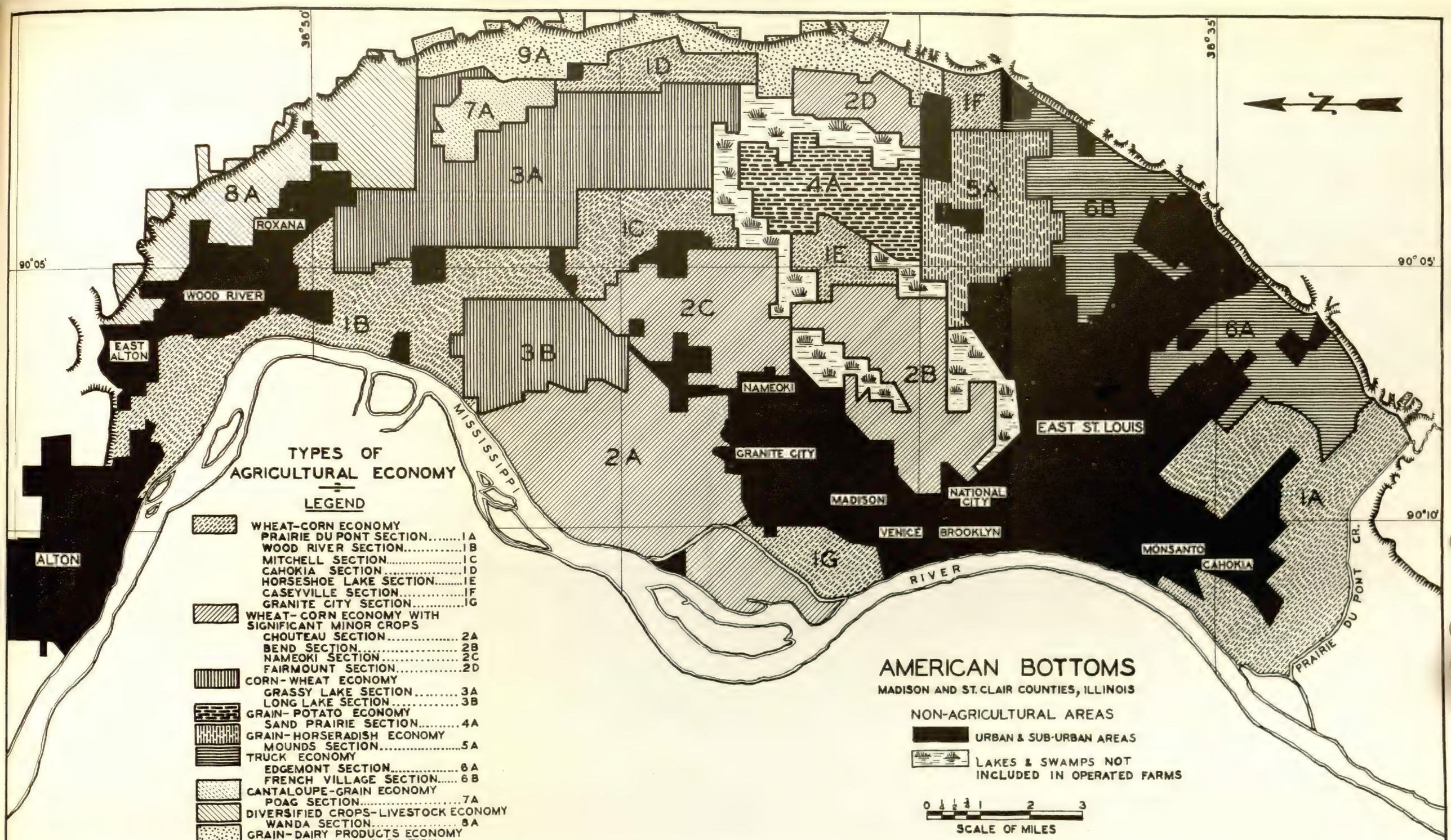
36°30'
36°35'
90°05'
90°10'
N
9A
1D
7A
3A
8A
ROXANA
WOOD RIVER
1C
4A
2D
1F
5A
6B
1E
2C
1B
3B
EAST ALTON
NAMEOKI
2B
6A
EAST ST. LOUIS
MISSISSIPPI
2A
GRANITE CITY
MADISON
NATIONAL CITY
1A
VENICE
BROOKLYN
1G
MONSANTO
CAHOKIA
ALTON
RIVER
PRAIRIE DU PONT CR.
TYPES OF AGRICULTURAL ECONOMY
LEGEND
WHEAT-CORN ECONOMY
PRAIRIE DU PONT SECTION....1A
WOOD RIVER SECTION....1B
MITCHELL SECTION....1C
CAHOKIA SECTION....1D
HORSESHOE LAKE SECTION....1E
CASEYVILLE SECTION....1F
GRANITE CITY SECTION....1G
WHEAT-CORN ECONOMY WITH SIGNIFICANT MINOR CROPS
CHOUTEAU SECTION....2A
BEND SECTION....2B
NAMEOKI SECTION....2C
FAIRMOUNT SECTION....2D
CORN-WHEAT ECONOMY
GRASSY LAKE SECTION....3A
LONG LAKE SECTION....3B
GRAIN-POTATO ECONOMY
SAND PRAIRIE SECTION....4A
GRAIN-HORSERADISH ECONOMY
MOUNDS SECTION....5A
TRUCK ECONOMY
EDGEMONT SECTION....6A
FRENCH VILLAGE SECTION....6B
CANTALOUPE-GRAIN ECONOMY
POAG SECTION....7A
DIVERSIFIED CROPS-LIVESTOCK ECONOMY
WANDA SECTION....8A
GRAIN-DAIRY PRODUCTS ECONOMY
CENTRAL BLUFFS SECTION....9A
AMERICAN BOTTOMS
MADISON AND ST. CLAIR COUNTIES, ILLINOIS
NON-AGRICULTURAL AREAS
URBAN & SUB-URBAN AREAS
LAKES & SWAMPS NOT INCLUDED IN OPERATED FARMS
0 1/4 1/2 3/4 1 2 3
SCALE OF MILES
FIELD WORK
MADISON CO., 1933
ST. CLAIR CO., 1934

FIGURE 17

In the "Southwestern Area" wheat is the the most important money crop, although the acreage of corn is slightly larger.[1] In contrast, the acreage of wheat is somewhat larger than that of corn in the American Bottoms. Aside from a similarity in the importance of wheat and corn, the American Bottoms differs substantially from the "Southwestern Area" in the slight dependence placed on livestock and livestock products. "The poor drainage on many of the bottom land farms is unfavorable to livestock production, as it frequently leads to insanitary conditions around barns and hog houses."[2] Although truck gardening is not important in the Southwestern Area at large, many farmers between East St. Louis and the bluffs have truck farms, and many grain farmers of the American Bottoms raise truck products as "side lines."

The Relationships of the Physical Environment to Agricultural Economy

Relief and drainage.—The most impressive characteristic of the American Bottoms, considered from the standpoint of a general panorama, is the nearly level appearance of its surface.[3] In addition to numerous flats, detailed observations reveal, low ridges, slashes, and inconspicuous slopes. These minor variations, because of their effect on surface drainage and the position of the water table, are exceedingly important. Over twenty-two per cent of the farm acreage is not under cultivation chiefly because of swamps, shallow lakes, and water-logged soils. Where adequate drainage has been provided, former swamps and lake floors, practically indistinguishable in appearance from adjoining areas, have been converted into cultivable land.

Since the flood plain has been created chiefly through the deposition of sediments by the Mississippi River, no parts of it, with the exception of a few semi-artificial mounds[4] and several alluvial fans along the base of the bluffs, are much above the mean stage level of 392.05 feet above mean sea level of the river at St. Louis.[5] The river is at flood stage at

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[1]Case and Meyers, *op. cit.*, pp. 182-84.

[2]*Ibid.*, p. 185.

[3]N. M. Fenneman, *Geology and Mineral Resources of the St. Louis Quadrangle* (Washington: Government Printing Office, 1911), pp. 11-12.

[4]Warren K. Moorehead, Jay L. B. Taylor, and Morris M. Leighton, *The Cahokia Mounds* (Urbana: University of Illinois, 1928), pp. 13-14.

[5]Unpublished chart, Engineers Office, Department of War, St. Louis, 1937.

a height of thirty feet on the river gauge at St. Louis.[1] It has been estimated that only about ten per cent of the American Bottoms is above a flood stage of thirty-five feet.[2] The somewhat precarious position of the flood plain is shown by the fact that the 1844 flood, the highest flood of the upper Mississippi River ever recorded, reached an elevation of 41.3 feet above zero on the St. Louis gauge.[3]

The surface waters drained across the flood plain include water emerging from the upland in addition to water originating on the flood plain. The American Bottoms, aside from small areas draining directly into the Mississippi River, is divided among the basins of Wood River, Cahokia Creek, and Prairie du Pont Creek (Fig 18). The Wood River basin includes three square miles of flood plain, the Cahokia Creek basin one hundred square miles, and the Prairie du Pont Creek basin thirty-six square miles.[4] In the absence of sharp divides on the flood plain, these figures are only approximately correct. The combined upland areas of the three drainage basins are practically four times as large as the combined lowland areas.

Wood River drains a few square miles of lowland located to the west of the Big Four Railroad and adjoining Alton (Fig. 18). The lowland area drained by Cahokia Creek is bounded on the west by the Big Four Railroad extending from East St. Louis northward to the bluffs near Upper Alton, on the south by the Pennsylvania Railroad extending from East St. Louis to the bluffs at Caseyville, and on the north and east by the bluffs. With the exception of a narrow strip of land along the Mississippi River, the Prairie du Pont Creek basin includes all the American Bottoms to the south of the low divide on which the Pennsylvania Railroad is located.

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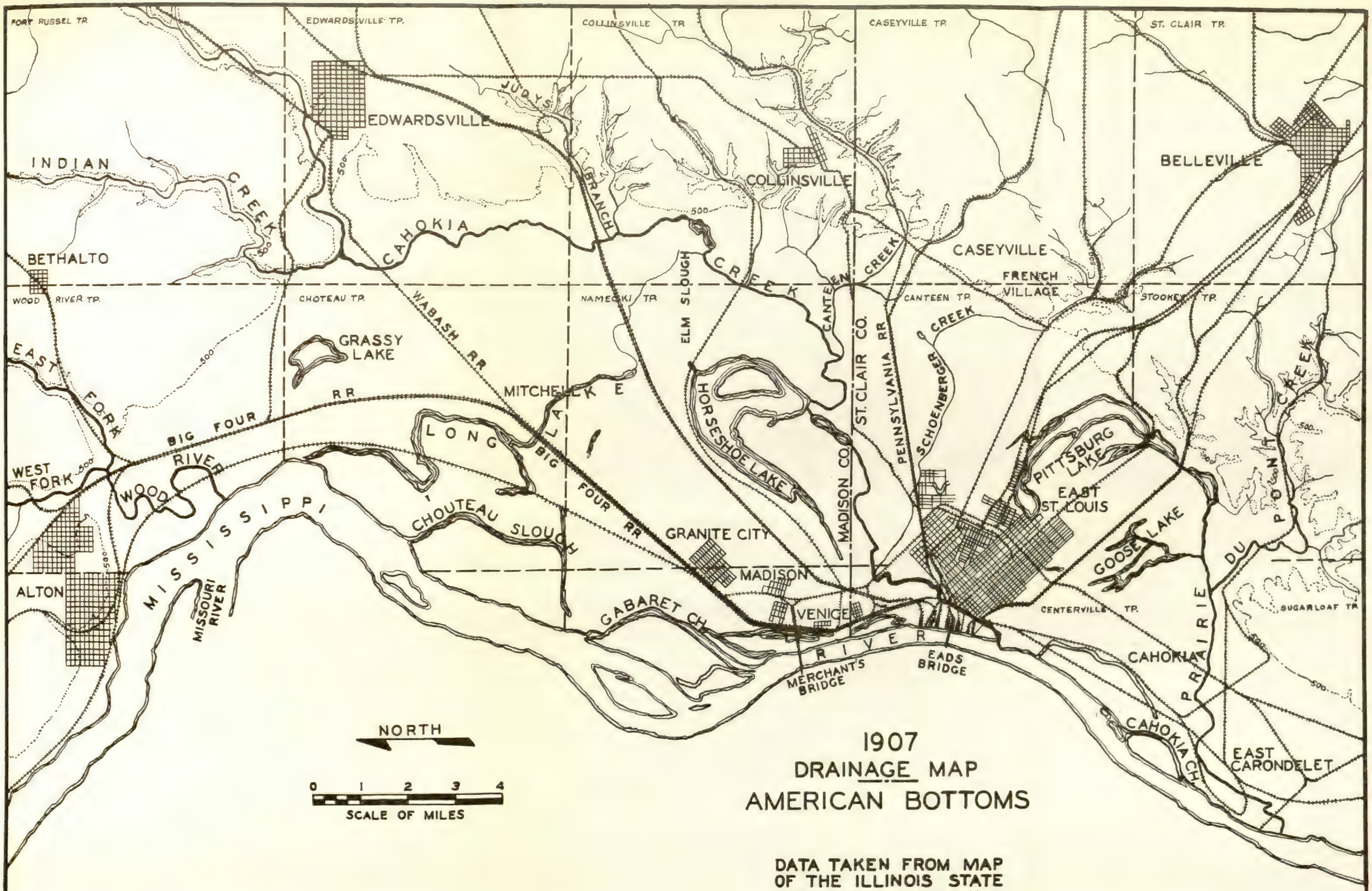
[1]Zero on the gauge is 379.796 feet above mean sea level.

[2]I. Bowman, and C. A. Reeds, *Water Resources of the East St. Louis District* (Urbana: University of Illinois, 1907,) p. 17.

[3]Unpublished chart, Engineers Office, Department of War, St. Louis, 1937.

[4]Edwin G. Helm, "The Levee and Drainage Problem of the American Bottoms," *Journal Association of Engineering Societies*, XXXV (1905), 92-93.



1907
DRAINAGE MAP
AMERICAN BOTTOMS

DATA TAKEN FROM MAP
OF THE ILLINOIS STATE
GEOLOGICAL SURVEY
1907

FIGURE 18

Under conditions prevailing before extensive improvements were effected (Fig. 18) the drainage of the flood plain was very unsatisfactory, and large areas still are uncultivable because of excess waters. Wood River meandered on the flood plain for a distance almost three times as great as the shortest distance between its point of exit from the bluffs and the Mississippi River. During a period of heavy rainfall in the upper basin, the flood plain section of the channel was unable to accommodate the water that flowed from the upland, and a large section of the adjoining flood plain was inundated.

On emerging from the bluffs, Cahokia Creek, instead of crossing the flood plain directly to the Mississippi only four and one-half miles away, flowed southward close to the foot of the bluffs, almost to the present boundary between Madison and St. Clair counties (Fig. 18). Thence its course extended in a generally southwesterly direction through East St. Louis to the Mississippi. The course which it followed across the flood plain was more than six times longer than the shortest possible route. Heavy local precipitation along its lower course, supplemented by an outpouring of water from the uplands, occasionally over-taxed the capacity of the channel and the natural reservoir called Horseshoe Lake. The ensuing floods inundated farm land and threatened East St. Louis.

Prairie du Pont Creek had a general course extending almost directly from the bluffs toward the Mississippi, but on nearing the river it turned southward and meandered on the flood plain for a distance of about five miles before emptying into the river. North of the creek the surface water moved slowly toward the bluffs where it formed a series of shallow lakes and swamps. No natural channel actively drained the water southward along the foot of the bluffs, but there was a poorly defined movement in that direction. Relatively large areas could not be placed under cultivation because of excess water. The upland section of the Prairie du Pont Basin is only twice the area of the lowland section, whereas the upland section of the Wood River Basin is thirty-nine times larger than the lowland section and the upland section of the Cahokia Basin is more than three and one-half times larger than its flood plain section. Moreover, lakes and swamps, particularly Pittsburg Lake, were effective natural reservoirs in the Prairie du Pont Basin. Consequently, local floods there were less threatening than those in the Wood River and Cahokia basins.

A major problem of individual farmers or of groups of farmers living on contiguous farms is to provide supplementary ditches to facilitate the movement of water to arterial channels. Effective land utilization

depends not only on flood control of the Mississippi River, but also on flood control of upland waters and on the rapid disposal of excess precipitation on the flood plain. Scarcely a year passes without hundreds of acres lying fallow because of excess water at the time when the ground should have been plowed or seeded. On many farms in any year the effects of dry spots and wet spots are reflected in variable yields. As already noted, swamps and lakes withhold large areas from any agricultural use.

Ground water.—Underlying the surface soils the alluvial deposits, which reach depths in excess of one hundred feet, are composed predominantly of porous sands. Studies made to discover the best location for deep wells to serve the upland city of Edwardsville indicate that there is a pronounced movement of underground water from the uplands toward the Mississippi River.[1] On many farms an ample domestic supply of water is secured merely by driving a screened pipe into the ground to a depth of ten or fifteen feet.

Large areas are cultivable only because of rapid under-ground drainage. Moreover, a recession of the water table caused by (a) a cycle of relatively dry years, (b) drainage improvements to facilitate surface movements of water, and (c) heavy withdrawals of ground water for urban and industrial uses, has extended substantially the cultivable areas.

Seldom are excellent yields secured on well-drained land and poorly-drained land during the same season. If there is an abundance of well-distributed precipitation, the well-drained soils yield the more heavily during a protracted summer drought. However, as in 1933, corn on well-drained land may be almost a complete loss while corn on poorly-drained land may yield heavily. Improved drainage has lessened the ability of some areas to withstand droughts but has brought under cultivation areas which are favored by seasons of scanty rainfall.

Soils.—Farmers of the American Bottoms refer only to three types of soils, viz: (a) clays or gumbo, (b) loams, and (c) sandy soils or sands. The clays are characteristic of low, poorly-drained areas or areas which formerly were inadequately drained. The sands are located chiefly on

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[1]Oral statements of officers of the Edwardsville Water Company, Edwardsville, Illinois.

ridges or relatively high flats. The loams have intermediate positions with reference to sands and clays or occupy higher land instead of sands.

The only significant area with clay soil is in the northern part of the American Bottoms (Fig. 19). It is relatively low and has poor drainage. In the northeastern part of the bottoms, a sand ridge is the backbone of an agricultural section (Figs. 17 and 19), and scattered patches of sand help to account for a diversity of crops in an agricultural section adjoining the urban centers of Wood River and Roxana. Loams cover a much larger acreage than clays and sands combined.

The loams, in general, are held in higher esteem than either the clays or sands. The loamy type of soil can be handled mechanically more readily than either clay or sand and is highly productive. Loams have considerable capacity to hold water and yet the particles of soil are sufficiently compact to retard its escape.

When clay is wet, it becomes sticky and large masses of soil particles cling together; when clay is dry, large cracks develop and the soil becomes so hard that an ordinary tractor cannot pull a plow through it. If the soil is neither too wet nor too dry, the preparation of a seed bed and cultivation are easy. If heavy rains occur every week or two during the growing season, gumbo soils tend to yield abundantly. The clay types are not in ill-repute because of a deficiency in plant food, but because of mechanical difficulties in tillage and unsatisfactory conditions of soil moisture that are sometimes encountered.

Because of the rapid disappearance of water and the loose cohesion of particles, sandy soils can be worked almost any time, although better when somewhat moist. However, plows are dulled quickly by the coarse heavy grains of sand. Since the sandy types are deficient in plant food, only such crops can be grown profitably on them as will stand a heavy outlay for fertilizers. In the Poag Section, where sandy soil has molded the crop pattern, a ridge with sandy soil is more highly valued than adjoining land with heavy loams (Figs. 17 and 19).

The differentiated agricultural economy of the American Bottoms is due in part to soil variations. Although wheat and corn are grown on both loams and clays, wheat acreage tends to become relatively more important on the clays. Potato and horseradish fields are almost wholly confined to loams. Trucking has reached its best development on loams. Perhaps the most distinctive adjustment of agriculture to a particular soil type is in the Poag Section, where cantaloupes and rye are grown almost exclusively on sands. Although the correlation is not perfect, since many other factors help to determine particular crops

in a given area, farmers in general show intelligence in the selection of crops which are adapted to soil characteristics.

Climate and weather.—Climate exercises a dominant influence on the types of crops that persist in a region over a long period of time. Weather is highly significant in determining the success or failure of crops in a particular season. The farmer's remote interest is in climate; his immediate interest is in weather. Since weather conditions from year to year are characterized by marked variations in the American Bottoms and adjoining areas, climatic data may vary materially from comparable weather data for a given year (Table 5). The weather conditions that prevailed at particular times during past years are not reliable indices as to weather conditions that will prevail at corresponding times during a current year. While the rule of averages reveals the mode, there is considerable variation in the particular time when different farmers engage in such activities as planting, cultivating, and harvesting. Such differences are due in part to individual interpretations of weather phenomena and their effects. Although a farmer may plan his work just as carefully one year as another, weather variations, especially as to precipitation and temperature, result in appreciably different yields. "If we get the right kind of weather, we shall have a good crop" is a current expression among farmers. Scarcely a year passes without the occurrence of some weather phenomena which the farmers consider unusual. Unusual weather phenomena may be considered normal occurrences of the American Bottoms.

The last killing frost in spring occurred on March 29th[1] in 1933; the first killing frost of autumn occurred on November 8th. The time span of 224 days was fifteen days longer than the average length of the growing season, which was a favorable span for raising the customary crops. The precipitation for March and April was slightly above normal; the precipitation for May was almost twice the normal amount (Fig. 20). The wet spring delayed planting and resulted in much fallow land, especially in poorly-drained sections. The mean temperatures for March, April, and May, were close to normal (Fig. 21). The mild, rainy weather for these months favored wheat, except where excess water remained too long on the surface. June, however, was the warmest June on record (1837-1933), and the second driest June. Wheat

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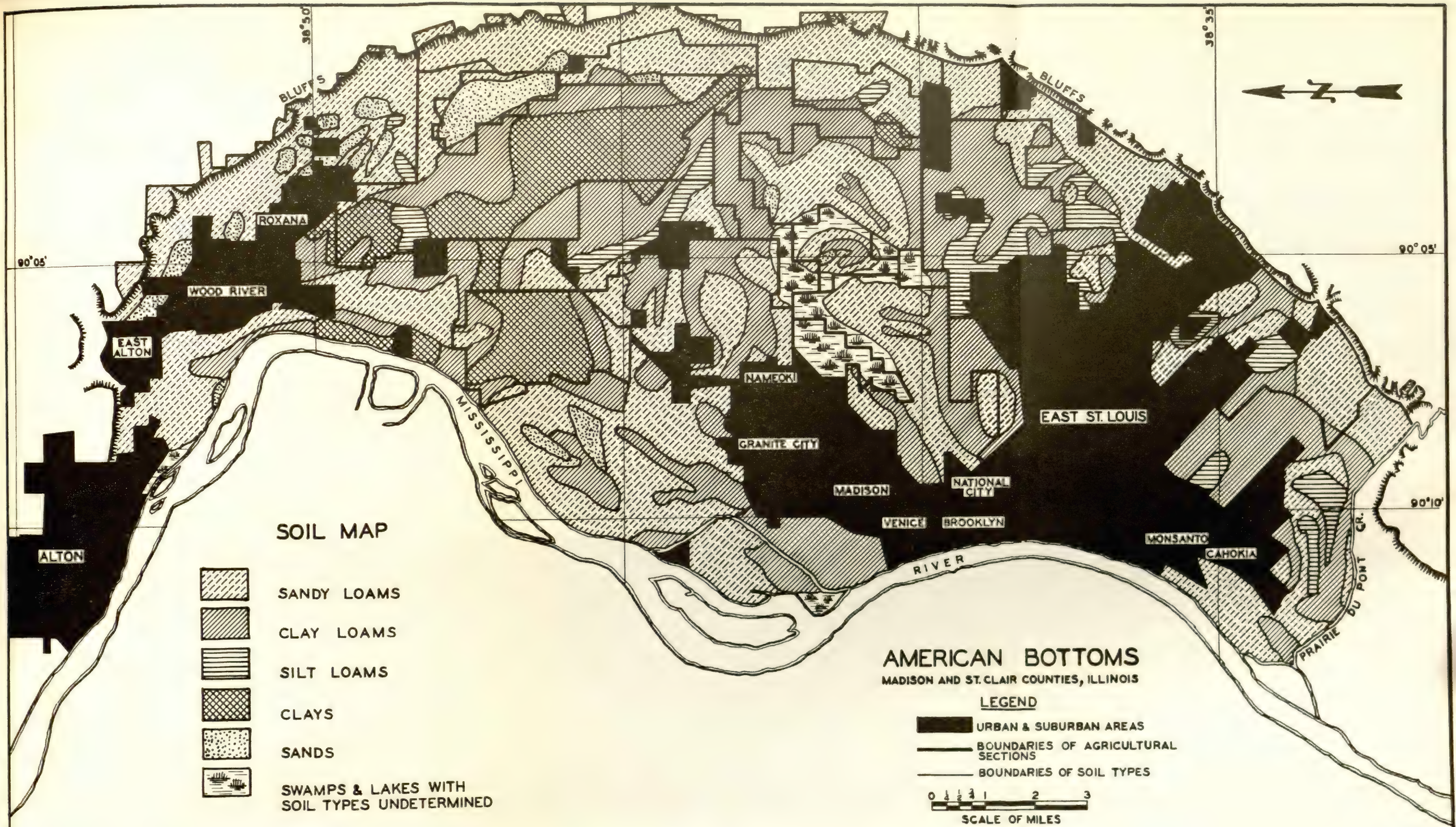
[1]Roscoe Nunn, *Annual Meteorological Summary for St. Louis, Missouri* (St. Louis: Weather Bureau, 1934), p. 2.



DATA ADAPTED FROM UNPUBLISHED SOIL MAPS
COMPILED BY THE UNIVERSITY OF ILLINOIS.
MADISON CO., 1922 ST. CLAIR CO., 1933

FIGURE 19

was far enough advanced, before the hot, dry weather began, to assure fairly satisfactory yields, although the quality was affected by shriveling. Corn fired badly and, adversely affected again in July and August by a marked deficiency in precipitation, was an almost complete failure. The graph (Fig. 20) does not show the degree of deficiency that existed in July because it includes a downpour of 3.72 inches that was confined chiefly to the east-central part of the city of St. Louis. The drought, beginning in June, in reality did not end until the fourth week in September (Fig. 20). The mean temperature for each month from February to September inclusive, excepting April, was above normal, which accentuated the effects of the drought. The fall rains, attended by mild temperatures, revived pastures but came too late to be of much benefit to field crops. The severe damage to crops was not due chiefly to a deficiency in precipitation for the year as a whole but to an unfortunate distribution during the year.

The last killing frost in the spring of 1934 occurred March 20th; the first killing frost in autumn occurred November 2d.[1] The time span of 219 days was ten days longer than the average length of the growing season. March, April, and May had rather mild temperatures but a marked deficiency of precipitation (Figs. 22 and 23). The wheat crop, as during the preceding year, came through in fair condition and provided the sole money crop for many farmers. The clay soils, too wet the preceding year, were too dry for the proper preparation of seed beds. For the first seven months of the year the total amount of precipitation for each month was below normal (Fig. 22). When the drought was ended by generous rainfall in August, the deficiency in precipitation for the year had reached 10.5 inches. The rains came too late to render much benefit to the field crops. Only eight years in the preceding ninety-eight had less precipitation than 1934. The effects of the drought were accentuated by the high temperatures and low relative humidity which generally prevailed. June, July, and the first half of August set a new record for a hot season. During the hottest day, July 24, when a maximum temperature of 110° was reached, the relative humidity at 1 P. M. was only thirteen per cent.

Deficiencies in precipitation have resulted in the disappearance of some swamps and shallow lakes. Farmers hold different opinions as to

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[1]Roscoe Nunn, *Annual Meteorological Summary for St. Louis, Missouri* (St. Louis: Weather Bureau, 1935), p. 2.

TABLE 5*

GENERAL CLIMATIC AND WEATHER DATA FOR ST. LOUIS, MO.

Mean annual precipitation	39.55 inches
Smallest amount of precipitation for a year (1930)	23.23 inches
Largest amount of precipitation for a year (1858)	68.83 inches
Mean annual temperature	56.00° F.
Lowest average annual temperature (1875)	52.80° F.
Highest average annual temperature (1922)	60.10° F.
Average date of last killing frost in spring	April 3
Earliest date of last killing frost in spring	Feb. 27, 1878
Latest date of last killing frost in spring	May 22, 1883
Average date of first killing frost in autumn	Oct. 29
Earliest date of first killing frost in autumn	Sept. 30, 1899
Latest date of first killing frost in autumn	Nov. 28, 1902
Average length of growing season	209 days
Shortest growing season on record (1875)	163 days
Longest growing season on record (1922)	253 days

*Data compiled from *Revised Bulletin W*, United States Weather Bureau (Washington: Government Printing Office, 1935), pp. 6, 15, 20, and 24.

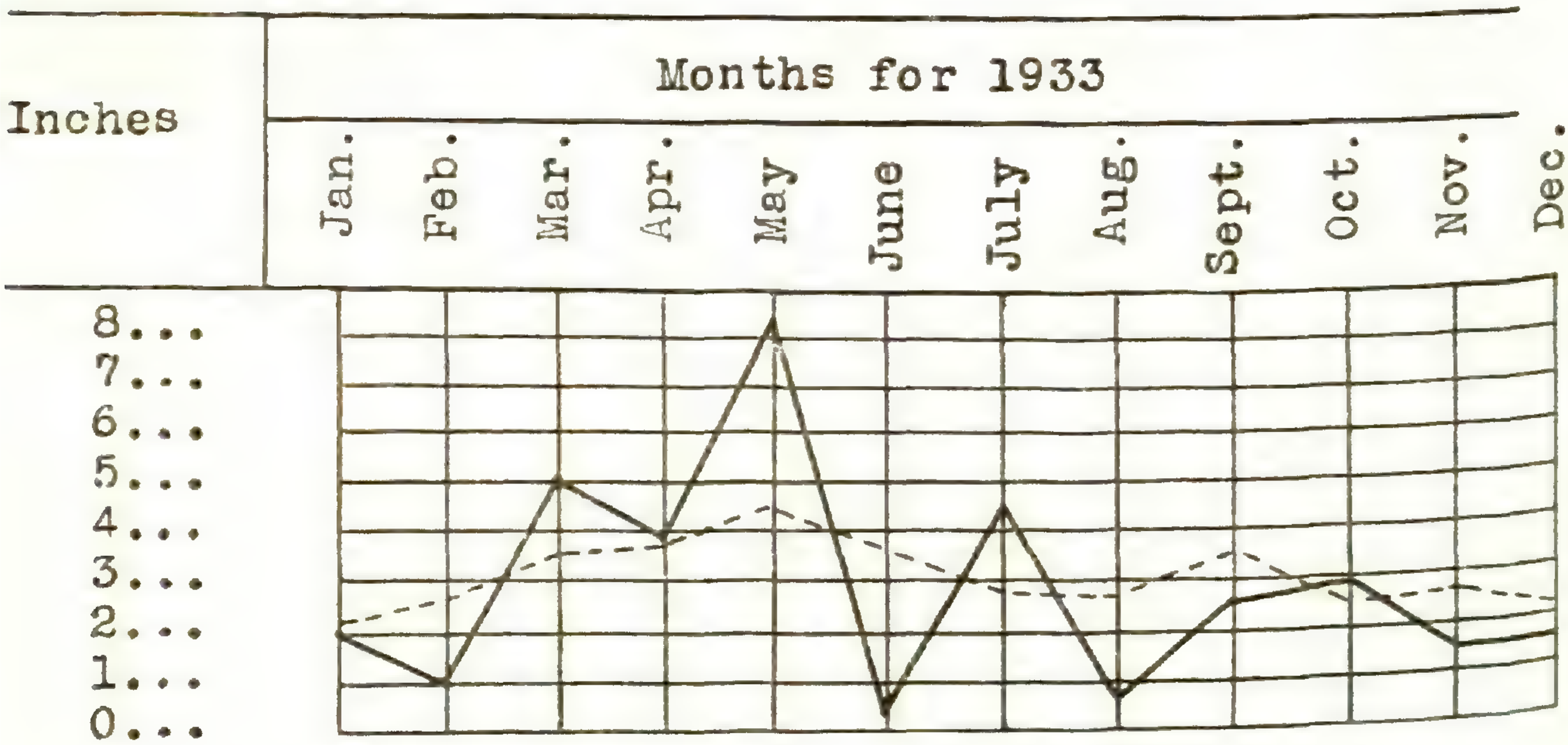
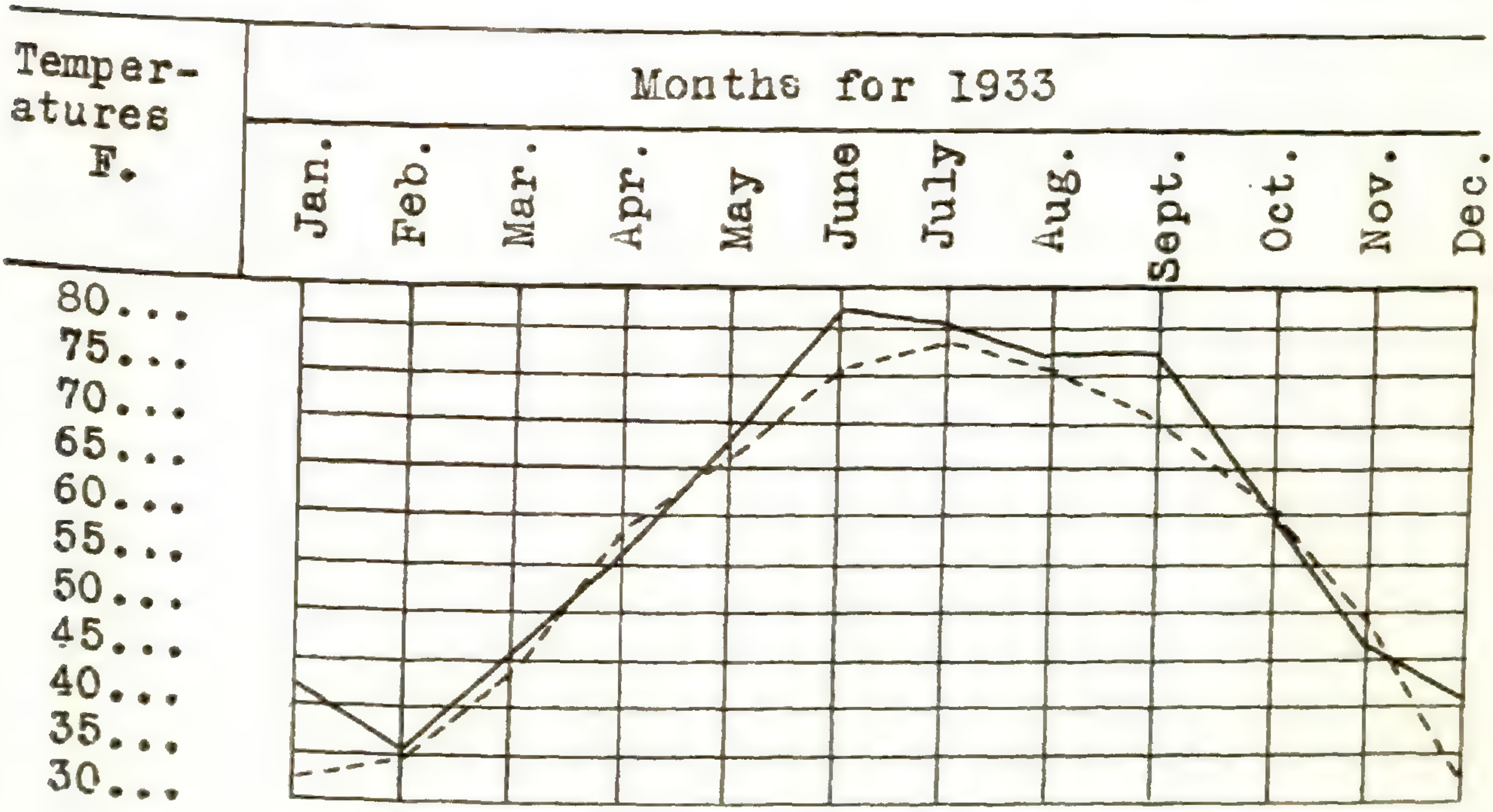


FIG. 20—Monthly precipitation for St. Louis (1933) †

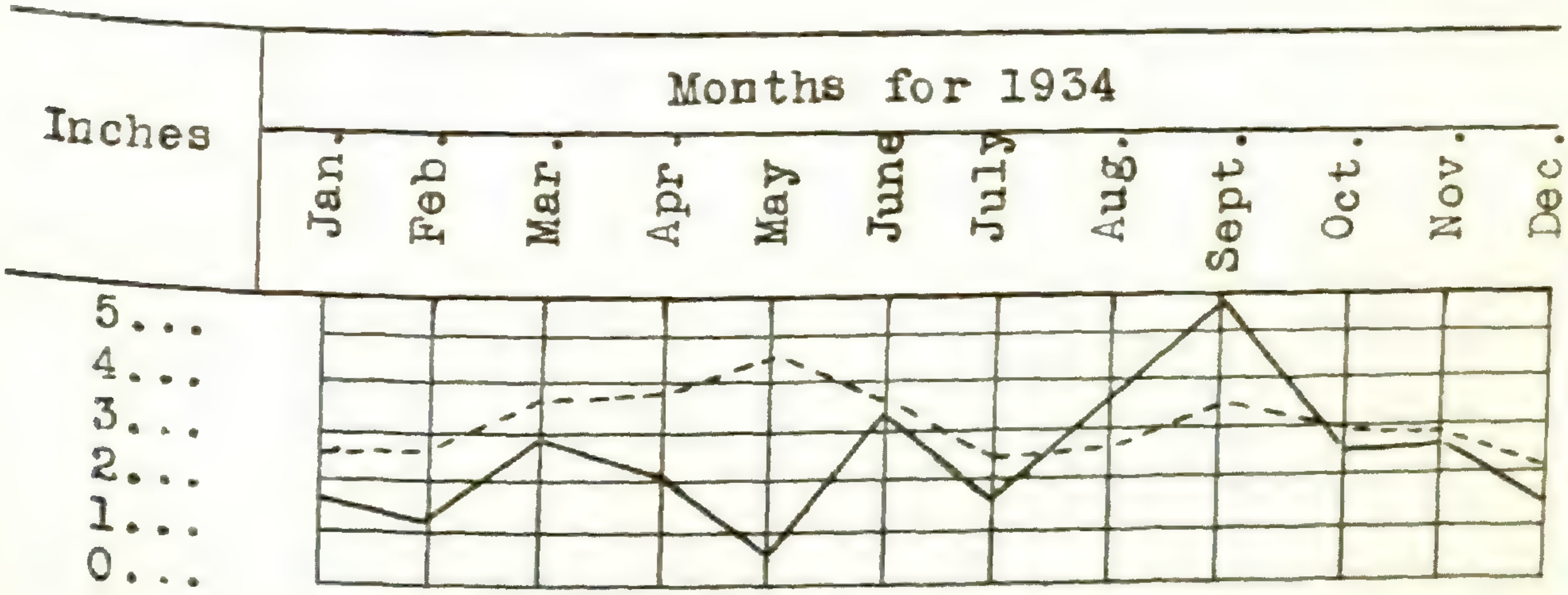
†Roscoe Nunn, *Annual Meteorological Summary for St. Louis, Mo.*, U. S. Department of Agriculture (St. Louis: Weather Bureau, 1934), pp. 3 and 6.

the relative importance of precipitation deficiency and drainage ditches in bringing about this result. Since 1930, when a cycle of relatively low precipitation began, the cultivated areas have been expanded to include former swamp land and even some lake floors (Figs. 24 and 25). The newly reclaimed land during these dry years has given larger yields of wheat and corn than those from much of the older agricultural land. The increasing dependence of farmers on marginal land suggests the probability of economic distress in a wet cycle.



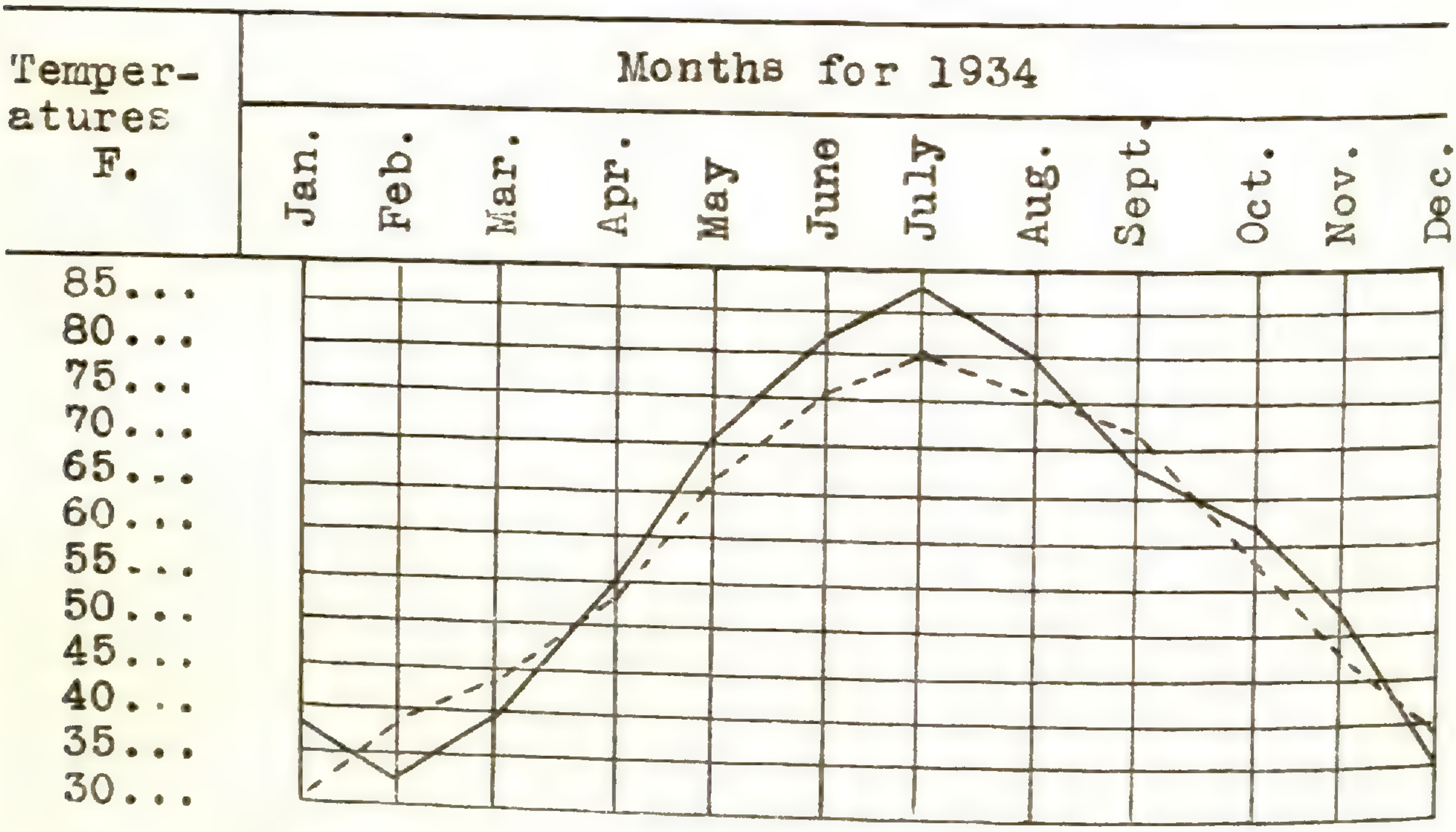
Temperatures during 1933.———— Normals.....

FIG. 21—Mean monthly temperatures for St. Louis (1933) derived from material *ibid.*



Precipitation during 1934.———— Normals.....

FIG. 22—Monthly precipitation for St. Louis (1934) derived from material *ibid.*, 1935, pp. 3, 6.



Temperatures during 1934. ———— Normals. . . . . .

FIG. 23—Mean monthly temperatures for St. Louis (1934) derived from material *ibid.*

THE RELATIONSHIPS OF OTHER TYPES OF CULTURAL PHENOMENA TO THE AGRICULTURAL PATTERN

Transportation routes.—Most of the network of railroads, chiefly converging on East St. Louis and Alton, was constructed before much serious thought had been given the problem of adequate drainage of the American Bottoms (Fig. 26). From breaks in the bluffs railroad lines were built across the flood plain to river terminals and, at a later date, to bridges providing direct connections with St. Louis. Numerous fills were constructed across swamps, sags, and shallow lakes without reference in most instances to the possible disturbance of natural drainage lines (Fig. 27). Lawsuits have been filed against railroad companies by farmers who claimed that their crops were damaged or ruined by floods which would have been harmless if railroad fills had not interfered with natural drainage.[1] There also have been disputes and legal entanglements between farmers and railroad companies over conditions existing at intersections of railroads and rural highways, where highway approaches are narrow and steep, or where low bridges with inadequate clearances have been constructed over highways (Fig. 28). Railroads present a problem in the construction of drainage ditches. The East Side Levee and Sanitary Board, in constructing the Cahokia Diversion Channel, had to bear the expense of constructing five railroad bridges.

[1]Helm, *op. cit.*, pp. 96-97.

So many railroad lines intervene between National City and the Mississippi River that a closed conduit has been substituted for an open channel in the construction of the Stockyards Diversion Channel.

Although railroad fills interfere with advancing waters, thus accentuating flood conditions on the exposed sides, they have been helpful in functioning as levees in the protection of urban as well as rural property. Proximity to great railroad terminals also favors the farmers in the disposal of products and in the purchase of manufactured goods.

The location of the American Bottoms with reference to great centers of traffic has been an important factor in providing the rural sections with excellent roads. All-weather roads converge on the five highway bridges connecting the East Side with St. Louis. A survey by the Illinois Highway Department in 1936 revealed the fact that the heaviest "through highway traffic" of the state, with the exception of that moving through Chicago, passes through East St. Louis.[1] The Alton-Edwardsville road (Route 159), the Chain of Rocks-Edwardsville road (Route U. S. 66), the Madison-Stallings road (Route 9), and the East St. Louis-Collinsville road (Route U. S. 40) are outstanding examples of arterial highways which incidentally serve rural communities of the American Bottoms (Fig. 26). The construction and maintenance of all-weather roads by state and national agencies have made it possible for the local road commissioners to maintain in excellent condition the reduced mileage of dirt roads.

Urbanization.—The location and expansion of urban and suburban centers have taken hundreds of acres of land permanently out of agriculture. As late as 1890, only a moderate encroachment on desirable agricultural lands had been made. Much of the area of East St. Louis was poorly drained and of slight agricultural value. The development of Madison, Granite City, and Nameoki, especially during the present century, has included excellent agricultural land lying between Horseshoe Lake and the Mississippi River. The lobes of settlement extending from the compactly developed portion of East St. Louis reflect the location of relatively well-drained land.[2]

Before 1907, the Illinois Glass Company and the Federal Lead Company had located industrial plants on the narrow flood plain immediately adjoining the upland of Alton, and the predecessor of the Western

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[1]Statement by Governor Horner at the dedication of the East St. Louis-Collinsville Road, October, 1936.

[2]National Resources Committee, *Regional Planning, Part II, St. Louis Region* (Washington: Department of the Interior, 1936), p. 17.

FIG. 24—A small clearing at the edge of a swamp near Horseshoe Lake.

FIG. 25—A temporary shelter for livestock on the former floor of a lake. The lake was noted for fish. Reclamation has been effected through the work of the East Side Levee and Sanitary Board.

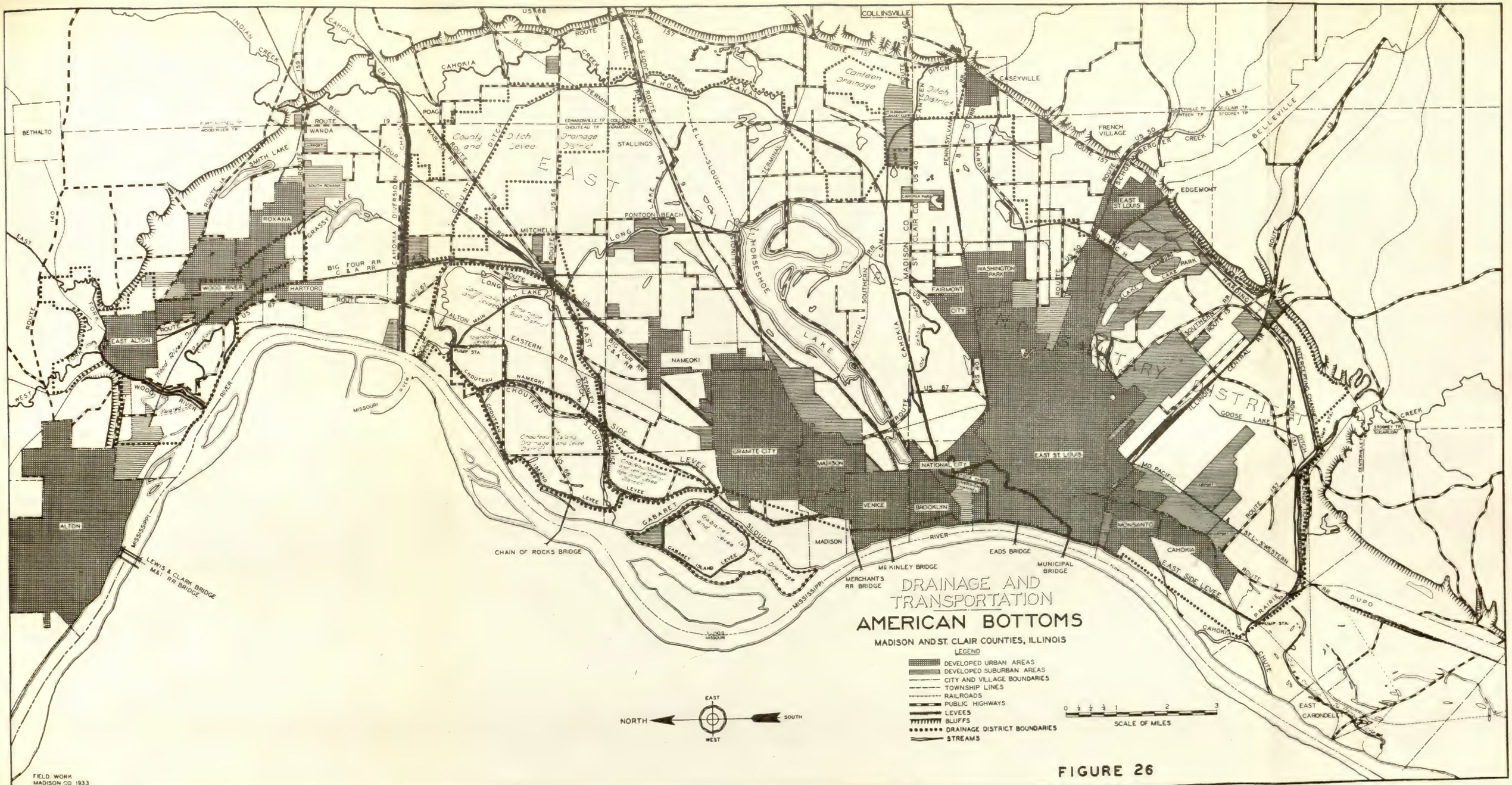
DRAINAGE AND TRANSPORTATION
AMERICAN BOTTOMS
MADISON AND ST. CLAIR COUNTIES, ILLINOIS
LEGEND
DEVELOPED URBAN AREAS
DEVELOPED SUBURBAN AREAS
CITY AND VILLAGE BOUNDARIES
TOWNSHIP LINES
RAILROADS
PUBLIC HIGHWAYS
LEVEES
BLUFFS
DRAINAGE DISTRICT BOUNDARIES
STREAMS
SCALE OF MILES
NORTH
SOUTH
EAST
WEST
FIELD WORK
MADISON CO 1933
ST CLAIR CO 1934
BETHALTO
ALTON
EAST ALTON
WOOD RIVER
ROXANA
SOUTH ROXANA
HARTFORD
WANDA
CAHOKIA
POAG
STALLINGS
MITCHELL
PONTOON BEACH
NAMEOKI
GRANITE CITY
MADISON
NATIONAL CITY
EAST ST LOUIS
BROOKLYN
VENICE
FAIRMONT CITY
WASHINGTON PARK
EDGEMONT
FRENCH VILLAGE
CASEYVILLE
COLLINSVILLE
MONSANTO
CAHOKIA
EAST CARONDELET
DUPO
CHAIN OF ROCKS BRIDGE
LEWIS & CLARK BRIDGE
M&T RR BRIDGE
MS KINLEY BRIDGE
MERCHANTS RR BRIDGE
EADS BRIDGE
MUNICIPAL BRIDGE
MISSISSIPPI RIVER
MISSOURI RIVER
ILLINOIS
MISSOURI
MO PACIFIC
ST L-SWESTERN
BIG FOUR RR
C & A RR
TERMINAL RR
ALTON & SOUTHERN RR
MADISON CO CANAL
ST CLAIR CO CANAL
HORSESHOE LAKE
LONG LAKE
GRASSY LAKE
SMITH LAKE
CANTEEN DRAINAGE DITCH
CANTEEN DITCH DISTRICT
COUNTY LAND DITCH LEVEE
DRAINAGE DISTRICT
CHOUTEAU ISLAND LEVEE AND DRAINAGE DISTRICT
GABARET ISLAND LEVEE AND DRAINAGE DISTRICT
EAST SIDE LEVEE
INTERCEPTING CHANNEL
STORMY TP SUGAREAF
CAHOKIA PARK
GOOSE LAKE
PRAIRIE DUPONT
PUMP STA.
FIGURE 26

FIG. 27—Railroad fill between East St. Louis and the bluffs.

FIG. 28—A low bridge over a public highway southeast of Roxana. This bridge has led to lawsuits between the railroad company and farmers because of inadequate clearance for farm machinery.

Cartridge Company had built a plant on the lowland at the junction of the East and West forks of Wood River. The land occupied by these industrial plants was of slight agricultural value, however, and practically all the employees of these companies lived on the upland of Alton.[1] Since 1907, when the Standard Oil Company located a refinery on agricultural land, which since has become part of the city of Wood River, urbanization of a large portion of the flood plain has been rapid (Fig. 1). Wood River and Roxana are located chiefly on a broad sandy ridge formerly noted for the production of cantaloupes and watermelons. Hartford occupies a ridge, once considered excellent agricultural land, between Grassy Lake and swamps along the Mississippi River. Suburban expansion associated with these settlements has been on relatively high, productive land.

Farmers of the American Bottoms believe that the pollution of the air by many industrial plants is detrimental to the growth of crops. They believe also that wheat and corn are less sensitive to such pollution than most crops. Through law suits brought against the Federal Lead Company, it was established legally that poisonous fumes emitted from the smokestack had injured crops over an area of several square miles. In order to carry the fumes to a height which would eliminate their deleterious effects, the company constructed a smokestack which has a diameter of forty feet at the base and towers to a height of 450 feet.

Various "nuisances," which may or may not be harmful, react unfavorably on the rural population. Granite City has an enclosed sewer to the river levee at the western edge of the city. However, from the river levee to Gabaret Slough, the sewage flows in an open ditch (Fig. 29). Two establishments near East St. Louis and one near Alton, with wretched-looking sheds and pens, have many hogs which are fattened on garbage. The village of Hartford owes its existence to the construction of a large tannery by the International Shoe Company. This company has attempted to establish a tannery in a location where there will be no objection to unpleasant odors.[2]

Urbanization has given a speculative value to adjoining agricultural land. Few non-residents who have purchased land as a speculation are interested in maintaining their farms either as to productivity or im-

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[1] *Alton Evening Telegraph*, Centennial Number, January 15, 1936.

[2] *Ibid.*

provements. In some instances, as near Roxana, subdivisions established from land taken out of cultivation have not been financially profitable (Fig. 30). The potential use of the land for industrial purposes is not conducive to the development of high class farms.

Proximity to urban centers helps to assure farmers an adequate supply of labor when their work load is heavy. However, the wages expected by urban dwellers deter farmers from engaging any more help than is absolutely necessary. In many instances farmers with the aid of members of their families are able to do most of the work by a heavy investment in labor-saving machinery and by stressing crops that do not require a large outlay for labor. Some farmers, attracted by relatively high urban wages, secure part-time employment in factories. Some young people work in urban centers but live on farms operated by their parents.

A moderate movement of city people into rural areas for the purpose of securing subsistence acreage is observable. However, farmers desirous of keeping out undesirable neighbors are reluctant to sell small portions of their farms. Real estate men, especially near East St. Louis, have been fairly successful in selling small tracts to city people. A few farmers with tractorized outfits live in urban centers either because (a) they are farming land which never had a set of improvements, or (b) former improvements have become worthless. Most farmers who live in urban communities farm small tracts intensively.

The adoption of comprehensive and substantial plans for adequate drainage and for the control of floods would not have been practicable without the additional wealth which urbanization has conferred on the American Bottoms. In 1907, when such improvements were undertaken extensively, over ninety per cent of the total assessed valuation of all taxable property of the American Bottoms, which reached a total slightly over one hundred million dollars, was on urban and suburban property.[1] From the standpoint of the value of property affected, the most important two levee and drainage districts of the American Bottoms are (a) the East Side Levee and Sanitary District and (b) the Wood River Drainage and Levee District (Fig. 26). Both districts

[1]Personal files of E. F. Harper, Chief Engineer for the East Side Levee and Sanitary District, East St. Louis, 1921.

FIG. 29—The Granite City sewer, from the top of the river levee.

FIG. 30—A premature subdivision of farm land for suburban development. Streets, bordered by rows of trees, have been provided, but no buildings have been constructed.

were organized primarily to provide protection for urban and suburban communities. Incidentally, thousands of acres of farm land also were benefited.

In the organization of the East Side Levee and Sanitary District (1907), the activating purpose of which was to provide protection for East St. Louis, it was deemed desirable to include over ninety-six square miles of flood plain.[1] Over two-thirds of the area thus included was classified as farm land. The western boundary of the district extending southward from Granite City was located along or near the bank of the Mississippi River in order to provide protection for developed urban centers and in anticipation of further suburban development southward from East St. Louis. Northward from Granite City, the boundary fronting the river was located a considerable distance from the river in order to provide for the expansion of river water during periods of severe floods. It was planned to construct a river levee just inside this western boundary. The section of the levee from Prairie du Pont Creek northward to Mitchell was constructed as planned. The levee was extended northward from Mitchell with a location outside the district, however, so as to effect a "tie in" with the south levee of the Cahokia Diversion Channel (Fig. 26). Hundreds of acres of farm land, located immediately to the south of the Cahokia Diversion Channel, were thus incidentally given protection against river floods, although outside the district.

To the north of the portion of East St. Louis which extends to the bluffs, a narrow belt of farms located on a relatively well-drained series of alluvial fans at the foot of the bluffs was not included in the district; however, to the south of this lobe of East St. Louis, the boundary line was extended along the foot of the bluffs where the axial line of drainage for this part of the flood plain is located.

Mr. E. F. Harper, Chief Engineer for the East Side Levee and Sanitary District, has listed the original objectives as follows:

> The general plan for the improvement of the District provides for the construction of the following works: (1) A diversion canal for Cahokia Creek, with levees on each side, from a point where the creek emerges from the bluffs, westwardly to the Mississippi River; (2) An improved channel for Prairie du Pont Creek, from the southeasterly corner of the District westwardly to Cahokia chute, connecting with the Mississippi River; (3) A levee along the river front from the Cahokia Creek diversion channel levee, to Prairie du Pont Creek channel, constructed to a grade 5 feet above that of the flood of 1844: (4) An improved channel for that

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[1] *Ibid.*

> portion of Cahokia Creek lying within the District and below the diversion canal; (5) Flood gates and a pumping station at the outlet of Harding Ditch and the outlet at Cahokia Slough; (6) A closed conduit, having a capacity of 2000 cubic feet per second, for an outlet for the improved channel of Cahokia Creek from the National Stock Yards to the river at Brooklyn; and (7) An intercepting canal along the easterly side of the District, for intercepting the flow of the creeks entering the District from the bluffs, from the Prairie du Pont channel to Judy's Branch.[1]

With the exception of the last one objective, all of these original purposes have been realized (Figs. 18 and 26). The closed conduit from the National Stockyards to the river was the last of six projects to be completed. The intercepting channel was begun in 1920 but was only partially completed when further work was stopped by court order.

Although Harding Ditch, extending northward from Prairie du Pont Creek had been constructed prior to 1907, it was of slight value because of sedimentation. It was widened, deepened, and extended northeastward to Caseyville. A tributary ditch was dug from the place where Schoenberger Creek emerges from the upland to the Harding Ditch. Horseshoe Lake, as a part of the improved Cahokia drainage system, and Pittsburg Lake, as a part of the Prairie du Pont drainage system, are considered invaluable as temporary reservoirs for flood waters.

Improvements effected by the East Side Levee and Sanitary Board led to the organization of two additional districts—namely, the County Ditch Drainage and Levee District and the Canteen Creek District (Fig. 26). The former was organized to extend a ditch from the northern terminous of the Cahokia Ditch northwestward toward the Cahokia Diversion Channel as a substitute for an earlier ditch that had almost disappeared through sedimentation. This district in part overlaps the East Side Levee and Sanitary District. The Canteen Creek District was organized for the purpose of substituting a ditch extending from the bluffs to the Cahokia Ditch for the meandering and shifting channel of Canteen Creek.

The improvements effected by the East Side Levee and Sanitary Board have beneficially affected farms far beyond the confines of the district. Threats of excess waters throughout both the Cahokia and Prairie du Pont basins have been reduced through (a) the diversion of upland water directly to the Mississippi River, (b) the construction and maintenance of fixed graded channels, (c) the construction of pumping stations where considered desirable to assist in the rapid removal of

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[1] *Ibid*

accumulating waters, (d) the maintenance of a low level of water in Horseshoe and Pittsburg lakes in order that flood waters can be accommodated, (e) the construction of a river levee designed to protect the levee and sanitary district from the highest probable flood of the Mississippi River, and (f) the confinement of channels by levees where deemed advisable.

The practical effects of the work of the Levee and Sanitary Board are visualized more readily in the rural than in the urban areas. Damage to crops because of unsatisfactory drainage has been lessened on hundreds of acres and a substantial acreage, formerly considered uncultivable, has been placed under cultivation. However, drainage improvements probably should not be given sole credit for the improved conditions. The practical importance of the river levee is reflected in the fact that a similar grade of farm can be sold with less difficulty and at a higher price per acre if it is located inside rather than outside the East Side Levee (Fig. 31).

The Wood River Drainage and Levee District was organized (1910) primarily to provide protection from upland waters for the grounds and buildings of two large industrial plants.[1] Incidentally, the boundaries of the district were drawn so as to include over one thousand acres of farm land. The channel of Wood River extending across the flood plain has been straightened (Figs. 18, 26, and 32), and the gradient of the channel at the foot of the bluffs has been increased by lowering the limestone floor of the channel so as to increase the down-river slope. These improvements have been effected to accelerate the rate of movement of bluff waters across the flood plain. A levee extending from the bluffs to a natural levee adjoining the Mississippi River has been placed on each side of the improved channel. The owners of protected farms are impressed with the effectiveness of the work done.

The foregoing discussion has presented the general relations which the rural population of the American Bottoms sustains toward the natural and cultural environments. The natural environment includes (a) a nearly flat or slightly undulating surface, (b) productive soils, (c) large areas of relatively well-drained land but an imperfectly developed drainage pattern as evidenced by the widespread distribution of lakes and swamps, (d) a low elevation relative to adjoining uplands and the Mississippi River which exposes the plain to flood hazards,

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[1]Pickels and Leonard, *op. cit.*, p. 46.

FIG. 31—A section of the river levee west of Granite City. Slag from steel mills has been placed on the outside slope. A dirt road parallels the outer side of the levee.

FIG. 32—The new mouth of Wood River with the Mississippi River in the distance. Rip rap has been placed on the inner slope of the levee where it extends across the former channel of Wood River.

(e) a mean annual precipitation of 39.55 inches with a late spring and early summer maximum, and (g) a growing season which averages 209 days in length.

The agricultural pattern is comprised predominantly of fields of crops interrupted here and there by sets of improvements. Locally differentiated crop combinations permit the resolution of the agricultural pattern into sections characterized by different types of economy. The structure of the agricultural pattern depends on (a) interrelationships within the pattern, (b) relationships with the natural environment, and (c) relationships with other types of cultural phenomena which are included in the areal complex of the American Bottoms.

PART II

OBSERVATIONS CONCERNING THE AGRICULTURAL ECONOMY OF THE AMERICAN BOTTOMS

The Relative Importance of Farm Acreage

The area of the American Bottoms is slightly in excess of one hundred thousand acres. The urban and suburban districts include approximately twenty-eight per cent of the total acreage. The combined acreage of (a) swamps and water bodies not associated with operated farms, (b) resort centers and scattered small settlements, (c) rural railroad property and highways, and (d) rural levees and drainage ditches, constitutes approximately seven per cent of the total acreage. The remaining acreage, which constitutes almost two-thirds of the total, is composed of operated farms.

Differentiated Agricultural Economies

An agricultural pattern with the differentiated types of economy represented (Fig. 17) has been promoted by (a) diversified conditions of the physical environment, (b) the presence of urban and suburban centers on the flood plain and also on the uplands on both sides of the Mississippi trough, and (c) individual and collective initiative. The outstanding characteristics of the sections with each type of agricultural economy are as follows:

1. The wheat-corn sections have a predominating acreage of sandy loams and a substantial acreage of clay loams. They also are characterized by excellent drainage of most of the field crop acreage. A distinct preference is shown for planting wheat in the sandy loams and corn in the clay loams. If a farm has both well-drained and poorly-drained land, wheat probably will be planted on the former and corn on the latter. Several considerations favor the production of wheat. (a) The labor requirements are light; (b) the actual cash outlay is small; (c) the soil

is not rapidly impoverished; (d) the net financial returns are considered as promising as for other kinds of field crops; (e) weeds are kept under control; (f) the grain has excellent keeping qualities; (g) a ready market prevails; and (h) it has been customary to devote a large acreage to wheat. Several considerations also favor the production of corn. (a) The labor requirements do not conflict seriously with the labor requirements of wheat; (b) the ears of corn and stover provide excellent feed for the limited head of live stock; and (c) the surplus is salable readily and provides a supplementary source of income. The extension of corn acreage at the expense of wheat acreage is not favored, however, because of the heavier labor requirements and the belief that wheat promises larger net returns.

2. In the sections where a wheat-corn economy is modified by significant minor crops, the conditions relative to soils, relief, and drainage are similar to those in the wheat-corn sections. Ready accessibility to markets, especially St. Louis and East St. Louis markets, and the influence of practical leaders have been important factors in the introduction of crops as "side lines." The important minor crops are sweet corn, potatoes, horseradish, and alfalfa. These minor crops are grown chiefly on sandy loams and, therefore, tend to compete for acreage with wheat rather than with corn.

3. The corn-wheat sections are characterized by clays (gumbo) and inadequate drainage. Corn is the major crop, not because the physical conditions are considered ideal, but because the farmers have not been able to discover some other staple crop that can adapt itself as satisfactorily to unfavorable soil conditions associated with excess waters or a deficiency of precipitation. Wheat grown on the clays produces tall weak stalks which rather readily lodge. Some seasons as in 1933 are more favorable for wheat than for corn. Such seasons customarily result in an increased acreage of wheat the succeeding year.

4. The isolation of the grain-potato section by swamps and water bodies has protected it from incursions of the potato blight which has affected the potato crop on most parts of the American Bottoms. Sandy loams which favor the production of wheat and corn also are considered ideally adapted to the growing of potatoes. Capable leadership among the farmers and cooperative endeavors have been helpful in the maintenance of the potato industry as a major farm project.

5. The grain-horseradish section was chiefly a corn-wheat section until about twenty years ago. The introduction of horseradish culture on a large scale has been favored (a) by the leadership of two

brothers, (b) by the presence of suitable loams, (c) by proximity to East St. Louis where unskilled laborers for farm work are available, and (d) by the discovery or creation of important markets for "radishes" in the East. A larger acreage of corn than of wheat is favored (a) by the heaviness of the loams and (b) by the fact that corn is considered a better crop than wheat in rotation with horseradish.

6. The truck sections adjoin East St. Louis and suburbs, which provide important markets for truck products and also contribute additional laborers as needed for field work. However, the most important markets for truck products are in St. Louis on the opposite side of the Mississippi River. Probably the best trucking area is located on an alluvial fan at the foot of the bluffs where a sandy loam type of soil prevails. This fan also is characterized by excellent drainage. The trucking area has been expanded, however, so as to include heavy soils and poorly-drained land. Due in part to physical differences among the truck farms and in part to differences in the ability of truck gardeners, the truck farms are not uniformly highly productive.

7. The cantaloupe-grain section has a sand ridge which favors the production of cantaloupes and rye. Watermelons formerly were important, but a blight has caused the farmers to curtail production of them. Wheat and corn are of some importance because of the extension of farms into the loams adjoining the sand ridge. Dependence is placed chiefly on local urban centers for the disposition of the melon crop.

8. The diversified crops-livestock section includes a part of the flood plain and a part of the rolling uplands. The loams of the flood plain portion are interspersed with sands. Diversity of soils and relief have contributed to a diversity of crops. Slopes unsuitable for cultivation on upland and sweet soils on the flood plain have contributed to the importance of pastures and hay fields. Excellent drainage has favored the keeping of livestock, while proximity to the Alton Industrial District provides an excellent market for dairy and poultry products.

9. The grain-dairy products section resembles the diversified products-livestock section. However, the flood plain portion has less diversity of soils and less diversity of crops. Moreover, the livestock industry is confined to the upland portion of the section where it is favored by excellent drainage and slopes better adapted to pasturage than to field crops.

Farming Operations

Tractors are in general use for plowing, disking, and harrowing, and for cutting small grain. Draft animals still are considered necessary for cultivating crops and for miscellaneous hauling. Fall plowing is customary, if weather conditions permit, in all fields where the crops are gathered in time. Fall plowing (a) assists in the control of weeds, (b) promotes the early decay of organic matter that is turned under, (c) exposes burrowing insects to the rigors of winter weather, (d) permits an improvement in the mechanical condition of the soil through the mellowing effects of freezing and thawing, and (e) furthers the work of producing crops during the next growing season. Wheat and rye are planted in the fall; practically all other planting is done during the first few weeks of the growing season. The length of the growing season provides a time span of several weeks during which fields can be seeded to various kinds of crops with a probability of maturing before the first killing frost of autumn. For the cultivation of various kinds of crops, riding cultivators, drawn by mules or possibly horses, are in common use except in fields of truck products where one-mule walking cultivators frequently are employed. Attempts are made to distribute the work of preparing seed beds, planting, cultivating, and harvesting so that a minimum of extra help will be necessary. In spite of such attempts practically every farmer requires help during some part of the year.

Trends

A consideration of the relations of the rural population to the physical and cultural environments suggests several distinctive trends.

1. The urban and suburban areas are continuing to expand, and it is conceivable that new centers of population will be established. More appealing opportunities in urban centers than on farms are inducing young people, when they become old enough to engage in vocational pursuits, to leave the farms. As improvements become obsolete, some farmers are moving to cities or villages but are continuing to operate their farms. The increasing importance of urban markets is stimulating farmers to engage in trucking or in the raising of "side line" crops. City people are purchasing relatively small acreage tracts with the purpose of engaging in subsistence farming while depending primarily on positions in urban centers.

2. Grain farmers are establishing "side line" crops, and grain farmers with "side line" crops are becoming truck gardeners. Large farms are

being subdivided because of the expanding truck acreage. Modest improvements are being established on the subdivisions, which are contributing to an increase in the density of population of the rural areas. The automobile and modern highways have minimized the advantage of a truck farm being located in proximity to a city where laborers are available. Farmers throughout the American Bottoms are becoming truck-minded.

3. The apparent prosperity of the farmers at the periphery of the American Bottoms along the foot of the bluffs is suggestive of the possibilities of extending the livestock industry, thus far confined to the relatively high land adjoining the bluffs, over the flood plain. Conditions are more favorable than formerly because of the effectiveness of drainage projects. The daily passage of trucks loaded with dairy products or poultry and eggs across the flood plain to urban markets impresses farmers with the importance of near-by markets for the sale of such products.

4. Flood control and drainage have contributed toward a more rapid depletion of soils, which is being reflected in somewhat reduced yields. An occasional pile of crushed limestone and scattered fields with soil-building crops suggest that the farmers are beginning to turn their attention to the conservation of soils. An increasing alternation of crops suggests that the thought trend of the farmers is in the direction of a systematic rotation of crops.

5. The introduction of the tractor has increased the capital expenditures for equipment. Draft animals still are considered necessary on most farms. A few farmers depend exclusively on tractors. The trend is toward the general use of labor-saving equipment with tractors entirely supplanting draft animals.

6. A general belief prevails among the farmers that in the somewhat remote future the agricultural pattern will have disappeared from the American Bottoms. They visualize the flood plain as one large industrial area. It is conceived that wage earners will live in modest homes on the flood plain, but the homes of the wealthier people will be placed on the adjoining bluffs. Such expectations tend to cause the farmers to value their land out of all proportion to its true worth in the production of crops.

APPENDIX

RESEARCH TECHNIQUE [1]

A general survey was made of the Mississippi flood plain between Alton and Chester, Illinois. A decision was reached to limit the detailed investigation to the notable expansion of this flood plain between Alton and Prairie du Pont Creek for the following reasons: (a) the area, embracing over one hundred thousand acres, was considered adequate; (b) the intermingling of rural and urban areas tended to set the widest part of the flood plain apart from the long narrow belt extending southward from the Prairie du Pont Creek to Chester; (c) the area apparently had a marked concentration of wealth, suggesting possibilities of an advanced state of relationships with the natural environment; and (d) the term, American Bottoms, once applied to the entire flood plain between Alton and Chester, locally had come to mean only the notably widened part of the flood plain, thus further suggesting its importance as a definite areal unit.

A superficial consideration of the cultural pattern of this restricted area suggested that a major line of geographic research might embrace (a) an agricultural economy, (b) an urban and suburban economy, (c) a transportation economy, (d) a study of flood control and drainage, or (e) a detailed study of these various lines of research singly and in combination. The decision was reached to stress the agricultural economy. The area presented an opportunity to study the effects on agriculture of urbanization and closely related cultural phenomena.

A continuous tract of land treated by the owner as a unit was considered an ownership farm. All land designated by acreage is considered farm land by the township assessors. However, for purposes of an agricultural study only those ownership units were included which were being used for agricultural purposes. The acreage of swamps was included only if it constituted a part of an operated farm. In the compilation of factual data, the ownership farm was considered the basic unit. From the standpoint of land utilization by farmers, it was recognized that the acreage under the control of each farmer is more im-

[1] An adaptation of a detailed discussion in the appendix of the dissertation.

portant than the acreage of an ownership farm. Consequently, the acreage under the control of each farmer also was tabulated.

At the outset of the study, an accurate base map was indispensable. Advance copies of topographic maps covering the American Bottoms were provided through the courtesy of members of the Illinois State Geological Survey. Photostats, with a scale of one inch to the mile, were made of the appropriate parts of these maps, and the photostats were combined to form one map. A base map was derived from this topographic map.

The location and acreage of each ownership farm was ascertained by a scrutiny of the assessors' books and cross-checked in the field by means of inquiries among farmers. Chief dependence for the delimitations of non-agricultural land — developed urban areas, developed suburban areas, and swamps not associated with operated farms — was placed on field work, cross-checked by data on topographic maps and plats of urban and suburban areas. Since an ownership farm was taken as the basic unit in collecting data, parts of the bluff slopes and u land were included if they were portions of farms which also included parts of the flood plain.

The boundaries of the ownership farms were placed on a base map Each farm was classified as to the type of agricultural economy represented on the basis of the composition of the field crop pattern. This map provided the data for the construction of a map showing the distribution of the sections with different types of agricultural economy.

Mr. R. S. Smith, Chief of the Soil Survey, College of Agriculture, the University of Illinois, provided advance sheets of a soil survey of St. Clair County and loaned the office copy of a soil map of Madison County. Mr. E. A. Norton, associated with the Soil Survey, supplied a table correlating the soil types of the two counties. The soil types were checked against the practical classification of farmers. The chief outcome of this cross-checking was the construction of a simplified soil map including five major types of soil, considered from the standpoint of recognized differences by practical farmers. The distribution of soil types has been shown on a map which includes the boundaries of the agricultural sections, in order to facilitate a comparative study of the relations of soil types to the types of agricultural economy.

Drainage and levee districts.—Private blue prints, showing farm boundaries and acreages, have been made of the several drainage and

levee districts. The drainage and levee districts provide a means of classifying farm lands. However, they have had only a moderate influence in the differentiation of types of agricultural economy. Consequently, it was considered preferable to treat them incidentally in relation to the agricultural sections with which they are associated.

Work sheets applicable to farm units.—Before undertaking the necessary field work, the writer made a work sheet which embraced the following topics:

> (*1*) location, (2) name of owner, (3) name of farmer, (4) number of years on the farm, (5) previous ownerships, (6) number of acres, (7) boundaries, (8) kinds of crops with acreage, (9) areal distribution of different kinds of crops, (10) comparison with previous year or years, (11) experimentations with new kinds of crops, (12) rotation of crops, (13) waste land and fallow land, (14) surface features, (15) natural and artificial drainage, (16) erosion and sedimentation, (17) kinds of soils and their distributions, (18) maintenance of soil fertility, (19) preparation of seed beds, (20) planting, (21) caring for growing crops, (22) garnering the crops, (23) disposition of crops, (24) gardens and fruit trees, (25) pastures, (26) livestock, (27) fences, (28) buildings, (29) domestic water supply, (30) water for livestock, (31) floods and flood protection, (32) favorable and unfavorable conditions affecting production, (33) supplementary means of making a living, (34) help needed, (35) seasonal distribution of work, (36) improvements or changes contemplated, (37) cooperation with neighbors, (38) influence of government, (39) influence of individuals or groups of individuals, (40) trading centers, (41) educational and religious facilities, (42) future plans, and (43) miscellaneous facts suggested by the particular farm and farmer.

The grouping of ownership farms.—A reconnaissance of the American Bottoms, before detailed work was begun, suggested a wheat-corn pattern with minor modifications. However, detailed tabulations of individual farms revealed significant differentiations as well as significant similarities in farm patterns. It became evident that differentiations were sufficient to justify the recognition of nine different types of agricultural economy. Furthermore, it became evident that contiguous farms in the same restricted neighborhood with a few exceptions had the same type of crop pattern. Thus it proved feasible to subdivide the rural area into sections with differentiated agricultural economies. The boundaries of the different sections suggested that (a) differences in soil types, (b) differences in relief, (c) proximity to population centers, (d) relative isolation because of swamps and water bodies, (e) the speculative value of land, and (f) local leadership were important factors in contributing to these differentiations. Furthermore, in most instances where an

individual ownership farm did not conform to the pattern of surrounding farms, it was found that the farm was being operated in conjunction with other farms. The total acreage managed by the same farmer almost invariably conformed to the local crop pattern.

Field work in 1933 and 1934.—Unless otherwise stated in the thesis, field data for the Madison County area were secured in 1933 and for the St. Clair County area in 1934. The weather conditions for both years were strikingly similar, and it is believed that the crop patterns in the American Bottoms were much the same for the two growing seasons.

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[1] A more comprehensive bibliography has been included in the complete dissertation.

Transactions of the Academy of Science
of St. Louis

VOLUME XXX, No. 5

ARCHAEOLOGICAL INVESTIGATIONS IN JEFFERSON COUNTY, MISSOURI 1939-40

Robert McCormick Adams

Issued May 31, 1941

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PREFACE

This report is the result of archaeological investigations by the Academy of Science of St. Louis and the Work Projects Administration of Missouri carried on in Jefferson County, Missouri, which lies along the Mississippi River immediately south of St. Louis.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge aid that he has received in connection with these archaeological investigations and this publication. Dean W. D. Shipton of Washington University and Secretary of the Academy of Science of St. Louis, was largely responsible for getting this project organized. Members of the Academy of Science of St. Louis have also contributed much of their time and have provided funds necessary to carry on the overhead expenses.

The Work Projects Administration officials in both St. Louis and Jefferson City, Missouri, were responsible for obtaining government funds without which the project could not have been carried out. Mr. A. C. Burrill, Curator of the Missouri Resources Museum gave the official support of his institution to the project.

Dr. Thorne Deuel, Chief of the Illinois State Museum, was our field and laboratory consultant and constructively criticized this manuscript. Dr. James B. Griffin of the Ceramic Repository for the Eastern United States analysed a representative sampling of pottery from most of the locations investigated. Mr. John Bennett, Mr. Clarence Jenni, Mr. Frank Magre, Dr. Harold Bulger and Dr. P. F. Titterington were consulted for technical help in scientific analysis.

Credit is due the people who conducted the technical aspects of the work. In this connection we must mention Mr. Edmund Winkler who took charge of the business arrangements of the project, Mr. Frank Foote for drawing the maps and features in the laboratory, Mr. Jay Sirolos for his photographic work and Mr. Ora Davis and Mr. Harry Hoff for superintending the field work and Mr. Clarence Garrett for his work as surveyor. My wife, Betty Adams, was largely responsible for the final editing of the manuscript.

We wish to thank the following people for their generosity in permitting us to carry on our investigations on their land: the Saint Joseph Lead Company and its agent, Mr. M. M. Huff, Mr. and Mrs. W. S. Boyce, Mr. J. A. Govro, Mr. and Mrs. H. C. McCormack, Mr. C. Rouggly, Mr. W. O. Schock, Miss Mary Jenni, The Pittsburgh Plate Glass Company, Mr. Gus Johannes and Mrs. D. J. Herrell.

Robert McCormick Adams

April, 1941

I. INTRODUCTION

ORGANIZATION INVOLVED AND AREA INVESTIGATED

This report is a description of archaeological investigations carried out by the Academy of Science of St. Louis and the Work Projects Administration in Jefferson County, Missouri, south of St. Louis during the year November 1, 1939 to November 1, 1940 inclusive. The work was accomplished under the direct auspices of the Academy, which provides a depository at The Adult Study Center of Washington University, and the many supplies and materials necessary to carry on the scientific survey. The Work Projects Administration provided the labor necessary to conduct the work. The Missouri Resources Museum at Jefferson City was the official sponsor, and The Smithsonian Institution at Washington approved the project. A representative ratio of duplicate materials excavated is to go to the State Museum and to the Smithsonian.

It was decided to write this report as soon after November 1st, 1940 as possible so that those who carry on archaeological investigations in other regions might have a chance to compare their results with ours. Therefore, it must be remembered that some of our conclusions are subject to alteration in the light of new materials obtained through continued investigations now being undertaken by the Academy. A few locations will be more completely investigated as soon as favorable conditions permit us to resume operation. Some fields containing remains of aboriginal villages were in alfalfa or otherwise not available for investigation.

GEOGRAPHY AND GEOLOGY

The area investigated during the 1939-1940 field season was the central and southeastern portions of Jefferson County, the northern boundary of which is St. Louis County. The eastern boundary of the county lies along the Mississippi River and the western boundary of the county is Franklin and Washington counties. Ste. Genevieve County and a tip of St. Francois County lie to the south.

Jefferson County is very hilly being a part of the Ozark foothills. Long lines of ridges extend in a general east to west direction. These hills are often forested except where too precipitous for vegetation or where cleared for farming. Besides the Mississippi River which serves as an eastern boundary for the county, the Meramec bounds the N.E. and N.W. sections of the county while the meandering Big River runs from south to north near the western edge of the county. Several tributary streams have their headwaters in Jefferson County and flow directly into the Mississippi. The most important south of the Meramec are Rock Creek, Glaize Creek, Sandy and Joachim Creeks and the Isle du Bois at the southeastern edge of the county. Bottomland is restricted to the tributary streams. There is very little bottomland along the Mississippi River itself because the channel lies against limestone bluffs.

Jefferson County lies on the northeastern flank of the Ozark dome. The rocks follow the dip of the area which is about three degrees to the northeast. There is considerable minor faulting and in the extreme southwest there is faulting of major proportions. The southwestern two-thirds of the county consists of rocks of Canadian and older age. From Festus to Kimmswick and inland ten miles from the Mississippi are rock exposures of the Ordovician series including the Everton, St. Peter, Joachim, Plattin, Decorah, Kimmswick, Fernvale and Maquoketa, with patches of the Mississippian or residual chert on the higher hills. North of Kimmswick the country rock is mostly Lower and Middle Mississippian rock of Glen Park, Bushberg, Fern Glen, Burlington, Keokuk, Warsaw and Spergen. There is no Silurian or Devonian rock which must have completely eroded.

Pennsylvanian or more recent rocks are not present but the Quaternary is represented by largely unconsolidated lacustrine deposits in terraces along the tributary streams. These terraces appear to have been formed by impounding when the glaciers dammed the water gaps or by checking of the Mississippi River depositing overloads of glacial debris. Some large igneous rocks and quartzites were possibly rafted into the area by ice.

Much of the Quaternary deposits contain fossiliferous deposits of mammalian bones. These have been picked up and dug out of bluish clay and gravel of ancient lake beds by stream action, uneroded remnants of which are found as residual pockets in various parts of the country. Usually they lie beneath heavy recent overburdens. Occasionally they are found in secondary position along present stream beds.[1]

PREVIOUS INVESTIGATIONS

Hardly an aboriginal mound has been untouched by excavators, and the plow has destroyed many of the superficial village deposits.

There have been a few temporary visits to the county by archaeologists in the past most of whom excavated small test trenches in mounds and graves. Chief among these have been David I. Bushnell, Jr., and Gerard Fowke both working for Smithsonian.

The results of Mr. Bushnell's investigations and conclusions for Jefferson County have been reported in the *Proceedings of the United States National Museum*.[2]

Mr. Fowke's investigations were carried on partly at the same location as those of Mr. Bushnell,[3] and partly along high

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[1]The section on geology was written from notes assembled by Mr. Clarence Jenni.

[2]"Archaeological Investigations in Ste. Genevieve County, Missouri," Vol. 46, pp. 642 and 655.

[3]"Mound and Salt Springs at Kimmswick, Missouri," Bureau of American Ethnology Annual Report No. 44, pp. 487 - 488.

ridges in the northwestern part of the county where he located aboriginal flint quarries.[1] Mr. Fowke also placed a trench in the famous bone bed at the union of Rock Creek and Little Rock (Black) Creek.[2]

The Academy is carrying on investigations here also with a view to determine whether or not man lived at the time of the mastodon.[3]

The author and Frank Magre carried on a surface survey over the county before the present investigation started. This survey served as the groundwork for our present investigations. The results were published in *The Missouri Archaeologist*.[4]

PURPOSE OF INVESTIGATION

This area in Jefferson County was chosen for investigation because of its nearness to the Mississippi River which served as a highway for primitive migration. It was selected also to conserve the rapidly disappearing evidence since all of the mounds in this area either have been pitted or destroyed, and the plow each year is removing much of the superficial village deposits. Two kinds of terrain, the high hills and the low bottom lands. also afforded us the possibility of obtaining cultural contrasts valuable for reconstructing the life of the past.

Our basic problems are fourfold:
(1) to determine, if possible, when man first arrived in the area, (2) to define and compare cultural complexes with those of other areas, (3) to determine culture sequences through typological

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[1]"Flint Quarries in Jefferson County," Bureau of American Ethnology Annual Report No. 44, pp. 533 - 36.

[2]"The Elephant Bed at Kimmswick, Missouri," Bureau of American Ethnology Annual Report No. 44, pp. 484 - 486.

[3]The results will be published in a separate bulletin of the Academy. The investigations are being carried out in co-operation with Dr. E. C. Olson, Vertebrate Paleontologist at the University of Chicago.

[4]"Archaeological Surface Survey of Jefferson County, Missouri," September 1939, pp. 11 - 23. At the present time a surface survey is being carried out in Ste. Genevieve County. The results of this work will appear in *The Missouri Archaeologist* to be published in the spring of 1941, Vol. 7, No. 1.

observations and stratigraphical methods, and (4) to isolate culture complexes found to be historic and compare them with prehistoric culture complexes. Some light was shed on (1), headway was made on (2) and (3), but no locations investigated have as yet been proven historic.[1]

METHODS OF RESEARCH

A laboratory in St. Louis affords space for cataloging, restoring, drafting, developing and printing, and library research. A crew of 15 to 20 workmen and a surveyor and photographer under the writer's supervision carried on the field work. All laboratory analysis was progressively synchronized with the field work. As soon as objects were excavated from the field they were marked and analyzed in the laboratory.

All locations were surveyed and grid systems were laid out for mounds or individual test trenches. More than 1000 photographs were taken and a log and descriptive feature sheets of important structural evidences were kept. The trowel and brush were used to point up vertical profiles such as intrusive pits and mound contours, horizontal structures or house outlines, refuse pits and burials, after which specific drawings and photographs were made step by step.

All artifacts and potsherds were recorded within two meter squares and ten centimeter depths.[2] "P" was used for the symbol of marking pottery; "A" was used for the symbol of marking artifacts or implements, and "M" was used for the symbol of marking animal bones. These were described on catalogue cards which are on file in the laboratory. Sites were indentified progressively as found by symbols as "v" for village, "o" for

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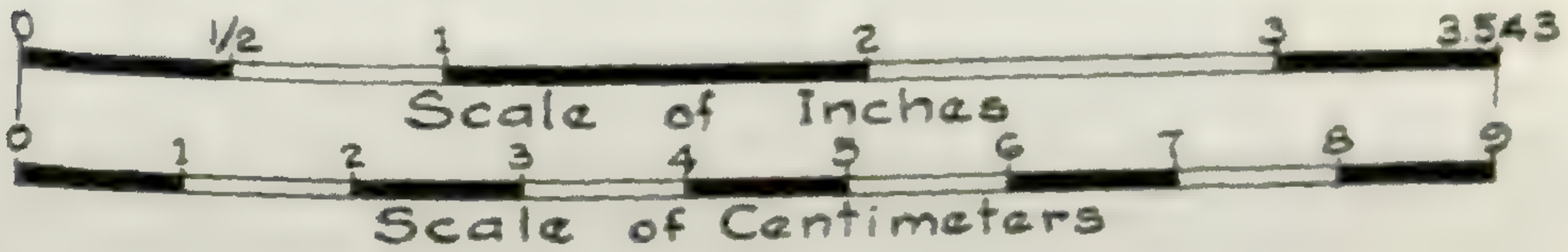
[1]All iron, crockery and coins found in mounds and villages has very definitely been shown to be in intrusive pits or above the plow line.

[2]The metric system was used for measurements except in the construction of topographical maps. The following is a conversion scale.



mound, "c" for cemetery, "s" for shelter, "p" for petroglyph locations and "m" for bone beds. Any physical grouping of sites such as a cemetery and village was called a location. Each successive location has been identified by a Roman numeral.[1]

Cultures have been identified on the basis of a compilation of lists of determinants or traits that are characteristic or diagnostic of cultural units. A cultural unit that has a number of common fundamental determinants is a pattern. A pattern is divided into phases which have a significant or minor number of traits in common. Phases are subdivided into smaller divisions which are known as aspects and have an approximate majority of determinants in common. Finer distinctions or cultural units that have large numbers of determinants result from further subdivision of the aspect into foci. A single cultural manifestation at any one location is a component but often there is evidence of more than one cultural unit on a site.

Cultural evidence at most of the sites that have been investigated[2] has been divided into patterns and phases only.

POTTERY ANALYSIS

Dr. James Griffin of the ceramic laboratory at the University of Michigan examined a collection of representative pottery sherds from sites in this area, except the large number of sherds from the Herrell village Jv55.[3] On the basis of this analysis a list of pottery wares was formulated that was usable for this area.[4]

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[1]We have used terms defined in the Glossary of *Rediscovering Illinois* by Dr. Fay Cooper Cole and Dr. Thorne Deuel except where we have found need to add, define or modify and redefine new terms.

[2]We have followed the pattern of cultural unit description officially recognized by scientists for the eastern half of the United States. A complete description of definitions of terms used in defining cultures in the eastern half of the United States and the Great Plains area may be found in *The Midwestern Taxonomic Method as an Aid to Archaeological Study* by W. C. McKern, *American Antiquity*, Vol. IV, No. 4, Nov. 11, 1939, pp. 301 - 313.

[3]The results of this study are being issued by Dr. Griffin in *The Missouri Archaeologist*, Vol. 7, No. 2, 1941.

[4]In our pottery classifications the community was first determined and the pottery description of each community was considered only as a part of the complete culture inventory.

Local names were attached to these pottery wares named from where they were first found in considerable numbers.

Stone Tempered Pottery

Herculaneum Cord Roughened (A)

This ware has a grit or limestone tempering. The interior is roughly smoothed but the exterior is invariably roughened with a cord wrapped paddle. The surface color is a tan to dark gray except when it is burned when it has a blackened surface. The hardness is 2.5 to 3 inclusive. The vessel shape seems to have included only the amphora usually with a slightly constricted neck. What little decoration there was was confined to reed punctate or finger pinched marks below the lip and cord wrapped cylinder impressions or plain punch marks on the lip surface. The closest analogy to this type is the subtype 2A ware described on page 42 of *Rediscovering Illinois.*

Herculaneum Reddish Cord Roughened (A_2)

This ware is very similar to Herculaneum Cord Roughened except that it has a reddish surface color and an added pot shape, a shallow bowl. This form may be atypical for only one rim sherd was found. The sherds of this ware were usually more eroded than the sherds of the Herculaneum Cord Roughened ware. Actually the difference between Herculaneum Cord Roughened and Herculaneum Reddish Cord Roughened may not be sufficiently distinct to justify their separation.

Hidden Valley Crushed Quartz (A_3)

This ware is distinguishable from the Herculaneum Cord Roughened and the Herculaneum Reddish Cord Roughened only by the use of crushed quartz as a tempering medium and a greater variation in thickness between the sherds.

Rouggly Grit (A_4)

This ware is coarse textured and thick for the small size of vessel it represents. The lip which is vertical is decidedly thinned. The tempering material consists of large and small grit

particles mixed into the clay. The surface is indented with deep punch marks executed at an angle with a blunt instrument. The closest analogy to this ware is the crushed rock ware from Fulton County described on page 48 of *Rediscovering Illinois* by Cole and Deuel. Thus far this ware has been found at only one site.

Shell Tempered Pottery

All of the above wares have grit tempering and generally a cord roughened surface. Differing from these wares in tempering and other considerations is the series of wares described below. These are shell tempered and generally have smoothed surfaces.

Imperial Plain (B)

This ware is shell tempered and has a smoothed brown to gray surface. The shell is crushed fine for smaller pots and coarse for large pots. The ware is harder (2.5 - 3) where the shell tempering is present but is soft (2 -2.5) where the tempering has leached out. There are several pot shapes including water bottles, beakers (beanpots), large and small shallow and deep bowls, bowl forms with flaring rims, seed bowls, plate and olla or jar forms. Occasionally the ware had a red slip and thick sherds from large shallow bowls often have fabric impressed surface finishes. Handles (loop type) are present on olla or jar forms. Effigy flanges are occasionally found from shallow bowls. The only decorations discovered thus far are the red slip mentioned above and etching after firing on the upper surface of the plate rims. The closest analogy to this ware is the "dull gray ware," described on p. 49 of *Rediscovering Illinois* and St. Clair Plain.

There appear to be subdivisions of this ware from the Herrell Village (Location XII, J^{v}55). A comprehensive report will be issued after investigations are completed at this important site.

St. Jo Polish Plain (B_2)

This ware is thin and hard (3.5). The tempering is finely crushed shells. The texture is compact and the surface has a

very high polish. It is either black or dark reddish brown. The only shape identifiable is the water bottle form. The closest analogy is the Polished Ware described on p. 51 of *Rediscovering Illinois.* This is not uncommon at Cahokia where it is known as Powell Polish Plain.

Crystal City Cord Marked (B_3)

This ware is similar to Herculaneum Cord Roughened but is tempered with shell fragments. Many sherds of this ware have been found at Cahokia.

Clay Tempered Pottery

Plattin Clay Tempered (C)

In addition to the stone tempered and shell tempered wares there is a clay tempered ware usually found as a common bowl and a bowl with a neck form having angular shoulders. This ware has been named Plattin Clay Tempered. The surface is cord roughened and the tempering is particles of clay. The hardness is 2.5 to 3 inclusive. There are two pot shapes, a shallow bowl and an olla or jar with a wide neck and slightly flaring rim, often with angular shoulders. The cord marking on the latter shapes were deep and below the angular shoulders. According to Dr. Griffin the closest analogy is the clay tempered ware found by Dr. A. R. Kelly at the Korando site in Jackson County, Illinois.

It is occasionally difficult to separate Herculaneum Cord Roughened, Herculaneum Reddish Buff, Crystal City Cord Roughened and Plattin Clay Tempered ware because the texture, hardness and surface treatment is often highly similar in all three wares. Sometimes the tempering appears to be a mixture of clay and grit or shell, or grit and shell. However, pottery shapes as indicated by large rim sherds usually closely follow pottery types.

LOCATIONS INVESTIGATED

A location is a localized area containing one or more sites A total of thirteen locations were wholly or partly investigated

during 1939-1940. (See Plate I.) Written permission from the owners was obtained before operations were begun.

Location I is on the Mississippi River Bluffs one-half mile south of the union of the Joachim and the Mississippi (SE ¼ Sec. 29 T.41 N.R.6E). This contains three small mounds and a small village site (Jo1, Jo2, Jo35, Jv5).

Location II is directly below location I and consists of five occupied small erosion cavities in the sides of the bluff 70 feet above the river (Js1, Js2, Js3, Js4, Js5).

Location III is a large rock shelter in Saint Peters sandstone located a few hundred meters west of highway 61-67, 1.5 miles due north of Crystal City, facing a small tributary of the Joachim (Js7), (U. S. Sur. 1986, SW Sec. 31-? T.41 N. R. 6E). It faces east. It was only partly excavated but work on it will be completed this year.[1]

Location IV (Jv32, Jo40)[2] is a village and low mound located on the left bank of the Plattin Creek one and one-half miles north of the hamlet of Plattin (U. S. Sur. 2177, SW ¼ Sec. 31-T, 40 N. R. 6E). As a part of the village site was in cultivation investigations were not completed here.

Location V (Jo57)[3] is a low mound without an accompanying village on a bluff over looking the left bank of the Plattin and lies half way between locations IV and VI (U. S. Sur. 411, N ½ Sec. 6?-T 39 R 6E).

Location VI is owned by Mr. H. C. McCormack. The location is a cemetery and village (Jc21, Jv93) on the right bank of the Plattin Creek directly across from the hamlet of Plattin. (U. S. Sur. 857, N ½ Sec. 6?, T 39 N R6E). The village was not investigated because it was in crops.

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[1]Locations I, II and III are owned by the St. Jo Lead Company.

[2]This site is owned by Mr. W. S. Boyce.

[3]Owned by Mr. J. A. Govro.

PLATE I

Map of Archaeological Locations Investigated

Location VII (J°19)[1] is a low mound without accompanying village site on a very high limestone bluff overlooking the Mississippi River a mile and one half south of the union of the Joachim and the Mississippi (SE ¼ Sec. 9 T 39 N, R 6E).

Location VIII (J^{s}30) is a shallow rock shelter at the south end of the county on the farm of Mr. C. E. Rouggly. It extends along the left bank of the Plattin. (U. S. Sur. 1285, SW ¼ Sec. 19? T 39 N, R 6E).

Location IX (J^{v}62)[2] is a village site on a high terrace or low ridge above the left bank of the Plattin a mile north of location IV. (U. S. Sur. 859 SE ¼ Sec. 30? T 40, R 6E).

Location XI (J°60) is a large mound owned by Miss Mary Jenni on a low ridge above the right bank of the Joachim a mile below its union with the Mississippi. No village was found in this immediate vicinity (U. S. Sur. 1906, about the center of Sec. B-T 40 N R 6E).

Location XII (J^{v}55) is a large village site on the left bank of Rock Creek just north of the town of Imperial. Highway 61-67 cuts through the east side of the site.[3] Test operations were begun on this site (Approx. SW ¼ Sec. 17 T 42 N, R 6E).

Location XIII (J^{m}2) is a bone bed containing extinct animal remains a half mile WNW of location XII (Approx. NW ¼ Sec. 17 T 42 N, R 6E).[4]

II. LOCATIONS ON HIGH RIDGES

ST. JO MOUNDS AND VILLAGES (LOCATION I)

J°1, J°2, J°35, J^{v}5

This picturesque location contained a group of three low mounds and a small village on the high limestone bluffs overlooking the Mississippi River one half mile south of the union of Joachim Creek and the Mississippi (Location I). Two of

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[1]This location is owned by Mr. W. O. Schock.
[2]Owned by the Pittsburgh Plate Glass Co.
[3]Owned by Mrs. D. J. Herrell.
[4]Owned by Mr. Gus Johannes.

these mounds J°1 and J°35, are adjacent to each other in a north-south line while the third, J°2 lies 150 meters to the west. J°1 was a small low domed mound approximately 10 meters in diameter and had a deep pit near the center. J°35 was a mound 14 x 18 meters and also had been pitted in several places near the center. J°2 was a small low domed mound 11 meters in diameter with a deep pit in the center. The ridge at this locality slopes eastward steeply toward the river and toward the west from J°2. There is a steep decline to the north to a point of the bluff where an old lead shot tower was used for the manufacture of bullets in the war of 1812.

A trench the width of J°1 was started at the north end of the mound and was carried forward. Profile pictures and drawings were made at two meter intervals. A thick layer of ash was encountered one meter from the north edge so the surface of the mound was stripped horizontally and a square layer of flat limestone slabs was found over a partly articulated burial of two adult individuals without grave furniture. The lower legs were disarticulated. (See Plate II A). Below the south edge of the mound lay an extended burial in a sub-mound pit with a projectile point. This burial was in extremely fragile state of preservation, appears to have been buried before the mound was constructed and probably represents an earlier component. The point had an expanding stem and was finely chipped. Sherds of the Herculaneum Cord Roughened variety and the Herculaneum Reddish Buff, broken worked flint fragments and a small isosceles projectile point coarsely chipped were found in the mound fill. The ash around the burials in the mound extended into the area occupied by the skeletons and certainly seems to have had ceremonial significance. It had been manufactured elsewhere as there was no charcoal nearby.

Inasmuch as sherds or artifacts were in the mound fill but not under it, and the characteristics of the sherds and artifacts were the same for both the village and mound fills, it is believed that the mound structure was of the same age as, or more recent than, the village.

J°2 was found to have been almost wholly destroyed by commercial excavators but the presence of a few scattered limestone slabs and a few human bones near the center of the mound attested to some sort of a rock formation in connection with human burials. A granite concave faced grinding stone and a limestone pestle stone found nearby, were found near the east edge of the mound.

Stemmed projectile points and Herculaneum Cord Roughened sherds were found in the mound fill. However it could not be determined if this mound was more recent or the same age as the village.

Two cuts were started at the south and north ends of J°35. Soon, however, rocks were discovered beneath the surface so the surface of the mound was stripped revealing a mantle of rocks on the north end of the mound and a mantle of rocks on the south end. Between these two formations at a depth of 40 centimeters was an outline of burned and discolored mound fill in the form of a rectangle with rounded corners. (See Plate II B). Just to one side of the center of this formation was a roughly circular fireplace and at the center of the south side was a discoloration that could have been a doorway. There were no post molds but a few fragments of charcoal from the fireplace were saved for dendrochronological study. Directly beneath this ceremonial structure at a depth of 40-50 centimeters below the floor of the ceremonial structure were the partially articulated remains of several adults, the upper extremities in complete disarticulation and partly missing. The mound fill also contained a few human fragments. The mound fill under the fireplace in the superimposed cermonial structure had been burned down to the burials. An extended adult lay to the east of the central graves. Many of the bones of this skeleton were missing. No grave furniture was found but a few mussel shells lay on the burial level on the original bluff surface between the central group and the extended skeleton. Herculaneum Cord Roughened pottery was found but there were also a few Imperial Plain sherds including a bean pot handle, which with small

PLATE II A
Burials in Mound Jo1

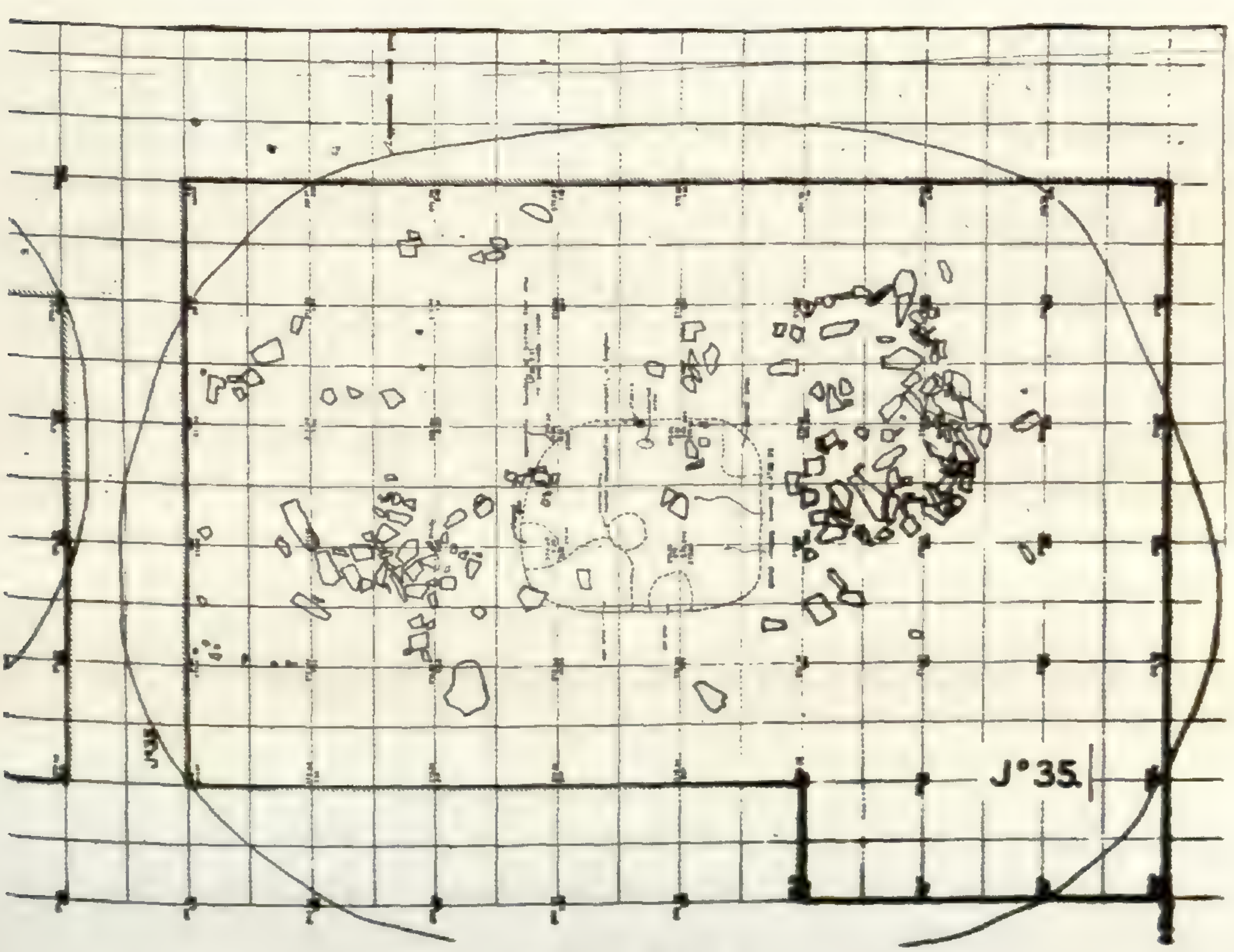

PLATE II B
Plan of Rock Placements Around Outline of Ceremonial Structure
which was over Burials in Jo35

coarsely chipped isosceles projectile points and coarsely chipped stemmed projectile points indicates a Woodland pattern influenced by Middle Mississippi. No pottery or other artifacts were found below the mound reflecting the possibility that this mound, like J°1, was of the same age as the village.

Several irregular burned areas were found close to the surface a few meters S.W. of J°35. These were temporary fireplaces. Potsherds and other artifacts were found near these fireplaces and in the trenches placed between J°2 and J°35. A few meters west of J°35 were a few flint rejects and large numbers of small flint chips indicating a small work shop. Besides stemmed projectile points a grooved ax of hematite, irregular hammerstones and Herculaneum Cord Roughened pottery were found. However, Imperial Plain ware was lacking. (See Plate III A). A few animal bones were found, fragments of the deer.

The structural differences and complete lack of Imperial Plain ware from J°1 indicates that J°1 and J°35 were different although related components. The extended burial below the south edge of J°1 is also in all probability a separate component and preceded the construction of J°1 and J°35 possibly by a considerable period of time. J°2 could not be compared with J°1 or J°35 although the presence of rocks and fragments of human burial in a mound suggested relationship with J°1 and J°35. J^{v}5 appears to have been occupied during the construction of the mounds as sherds were found in the mound fill although they were not present under any mound. The village and mound complex all seem to belong to a Woodland Pattern with Mississippi influence (see also trait analysis charts in Section V).

THE GOVRO MOUND (LOCATION V)
J°57

The Govro mound has no village near it. It is also on a high bluff but overlooks Plattin Creek above the left bank. It is a long low mound 27 meters by 13 meters and was less than 1 meter high before investigations. The long axis is in an ENE by WSW direction. The bluff dips sharply on either side of the long axis but slopes off more gradually from either end of the

mound. The mound was staked off and two trenches were started at either end of the long axis. The mound was stripped but large rocks and features were left in position. It was found that the whole central portion of the mound had been intensively pitted by commercial diggers. One of these diggers had left a penny dated 1892 at the bottom of one of the pits. However, the rest of the mound had not been disturbed. The original mound builders constructed a number of platforms of irregular residual flint. Those platforms when undisturbed were small and approximately a meter in diameter. They seem to have been made to represent animal outlines. Legs and a head with a rounded body is apparent in the platform near the WSW end of the mound. This may represent the bear. Fifty centimeters from this platform was a smaller irregular oval shaped platform with a crude grooved ax of granite which had apparently been used to break up the rocks. Thirteen meters to the east of this platform was another with an outline representation of a tail, legs and head with antlers, probably a deer.

It is possible that other platforms were placed near to the center of the mound but these must have been destroyed by the commercial diggers.

Two intrusive burials were found near the WSW end of the long axis of the mound. One of these was a tightly flexed adult covered with a layer of limestone slabs; the other was an ossuary containing long bones and decapitated skulls of several adults. The skulls had been broken off above the preauricular point, inion and glabella. The mantle rocks of the primary mound had not been replaced over the burial. (See Plate III B).

Two more intrusive burials of adults were let down into a trench and placed below the base of the mound in two pits after which the trench was filled with black loam that had been brought up from bottomland and along the Plattin Creek. These burials were along one side of the long axis. Both of the burials were extended but the pits were so small that the legs were drawn up. One of the pits was lined on the bottom with flat limestone slabs. A split animal bone hair ornament lay partly under the occipit.

PLATE III A
Typical Artifacts and Sherds from the St. Jo Mounds and Village
(For description see Plate XII A)

PLATE III B
Stripped Mound Jo57 showing two Intrusive Burials and Rock Platform in Position

Only a few flint rejects, hammerstones, and the bone ornament were found in the mound. Not a fragment of pottery was found either in the mound fill or in trenches excavated around the mound. The primary mound with effigy stone platforms, the tightly bound intrusive burial, the ossuary all seem to represent different events. The two extended sub-mound pit burials also seem to have been one event separate from the primary mound, the flexed burial and the ossuary.

THE SCHOCK MOUND (LOCATION VII)

Jo19

Like the St. Jo mounds, the Schock mound is located on top of limestone bluffs overlooking the Mississippi River, but there is no surrounding village site. The bluff at this point is known locally as Buck Knob. The mound is low-domed and is small but the bluff slopes sharply off on the north, east and south giving the impression of considerable height. During the course of investigation it was found that most of the northern half of the mound had been excavated by commercial diggers and there was a very deep and extensive pit at the center when we began work. The mound had been covered with angular chert blocks and just southeast of the center was a rectangular flat limestone slab platform at the base of the mound containing four groups of extremely fragmentary bundle burials of adults. There was no grave furniture. Over the edge of the platform and partly over the burials was an oval vault without roof made up of angular flint residual blocks. (See Plate IV A). After dirt fill had been placed in the vault, a crude wooden structure was placed along the upper inside edge of the vault and a fire was kindled which discolored the vault fill down to the burials. Some of the lower ends of charred posts were still in position. Beneath the rectangular platform was a narrow deep pit containing fragments of charcoal and ash. The angular flint rock mound was erected to enclose the vault and over the mound fill surrounding it. Although a very thin layer of humus covered this rock mound it is possible that it was the product of later accumulation of vegetable matter. The northeast corner of the vault had been disturbed.

Only a few sherds were found in the mound fill and not a single indentifiable artifact. Curiously enough these sherds were Imperial Plain and one had a heavy red slip. Two years ago the author found a tetrapod pot with a heavy red slip in the tavern belonging to Paul Franz at House Springs in the western part of the county. Mr. Franz stated that the man who presented it to him dug it up from the mound on Buck Knob. The pot had had a vertical neck which was missing and a wide but short body. The pot is Imperial Plain and had a rose-red slip. In view of the discovery of the red slip sherd from the mound it is highly possible that the pot had been dug out of the northern half of the mound. However, we cannot be absolutely certain that this sherd belonged to the missing neck of the pot.

III. LOCATIONS ON LOWLANDS

THE PITTSBURGH VILLAGE (LOCATION IX)

Jv62

This site is in a level area on a low ridge or high second terrace above the left bank of Plattin Creek. Fragments of long stemmed projectile points have been gathered from the surface for a long time by local amateurs. Of over 40 small test trenches excavated, evidence of only three temporary fireplaces close to the surface but widely separated from each other were found. Most of the test trenches yielded no aboriginal remains. No evidence of house structures was found. A few fragments of pottery and 18 stone implements were found. All of the pottery was of Herculaneum Cord Roughened ware. The tempering is very fine and there appear to be fragments of clay and possibly organic tempering intermixed with the grit. A crude round burned clay disc with a small concavity on one side was also found. The chipped stonework consists of short rather broad expanding-stemmed base points, an asymmetric knife and an oval blade knife broader at one end than at the other. A thin limestone ax with flaring bit and small irregular igneous pebbles with flat grinding surfaces were also found. In view of the large number of small test trenches it is believed that a representative cross-section of this site was obtained in spite of the scarcity of remains. Erosion by surface water and plow action

probably has destroyed much of the formerly intact aboriginal strata. Animal bones were almost completely absent. The village is probably an early component of the Woodland pattern.

THE BOYCE MOUND AND VILLAGE (LOCATION IV)
J°40, J^{v}32

The Boyce mound J°40 and village site J^{v}32 lie on a low second terrace along the left bank of the Plattin Creek two miles north of Plattin. A small portion of the site to the east occupies bottomland. Fragments of pottery and artifacts have been picked up on the surface for a long time and their distribution tends to indicate the boundaries of the aboriginal village which extends 400 meters north and south and not more than 50 meters east and west along the low second terrace. Near the northern limits of this location in a field now under alfafa cultivation, stone box graves with extended burials and water bottles have been found. The mound (100 - 150 meters south of the cemetery) before investigation was low, being only about 50 centimeters high. According to Mr. Boyce the mound was graded many years ago to facilitate farming operations. Most of the surface material has been piled up south of this mound.

Two trenches were started at the east and west boundaries of the site respectively. Unusual dark humus was found down to a depth of 50 to 100 centimeters below the edge of the mound. Mr. Boyce's statement that the mound had been graded was definitely demonstrated. The lensing indicating separate loads of dirt in the mound had almost been destroyed. It had probably once been a steep sided mound of much greater height.

Three very important formations were found at the base of the mound J°40. At the northeast corner of the mound were the burned remains of a rectangular house with rounded corners. At nearly the exact center of the mound were the ashes of a deer, presumably sacrificed and lying over the powdered remnants of a slightly concave container of bark by means of which it had been carried from the fireplace. Two meters to the east of this was a deep and narrow refuse pit containing

only dark decayed vegetable matter extending into the sterile sub-mound area. The house remains, the ashes and the pit were all on the same level indicating that the mound had probably been erected over all three formations.

The house was built by sinking poles vertically into the ground enclosing a rectangular floor space. The bottoms of these posts had been cut into a chisel shape before they were placed into the ground. The corners of the structure did not seem to have had posts in them. The house had not been completely burned to ashes. The fire had been put out while still smoldering so that large portions of intact wattle work of the collapsed walls (intertwining wall support members of small branches) lay on the floor. (See Plate IV B). Two or three fragments of charred grass thatch lay above the wattle work indicating that the roof and possibly also the walls were of thatch. A large crushed olla with flaring rim or jar lay just west of the center while two small ollas with flaring rims or jars lay near a mass of corn in the northwest quadrant. There was evidence of a small fireplace indicated by a roughly circular burned stain on the floor at the north end of the structure.

Many test trenches were placed in the village, particularly to the south of the immediate mound area. Some of these trenches were expanded when any feature of importance was found in them. It was found that the village occupied the higher second terrace and appeared to extend also into the low bottomland. One feature was found along the slope between the bottomland and second terrace. It was the wall outlines of several superimposed and possibly rebuilt aboriginal houses. The eastern extension of structures, lying in the bottomland, were so close to the surface that they had been destroyed by surface water and plow erosion. Furthermore structure outlines were more clearly visible and easy to locate on the slope between the first and second terraces because the black humus was less dark possibly because erosion had stripped most of the humus from the lower first terrace. The floor of the houses had been destroyed but a group of three small circular clay fireplaces close together near a mass of charred corn was found belonging

PLATE IV A

View of Stone Vault in Mound Jo19

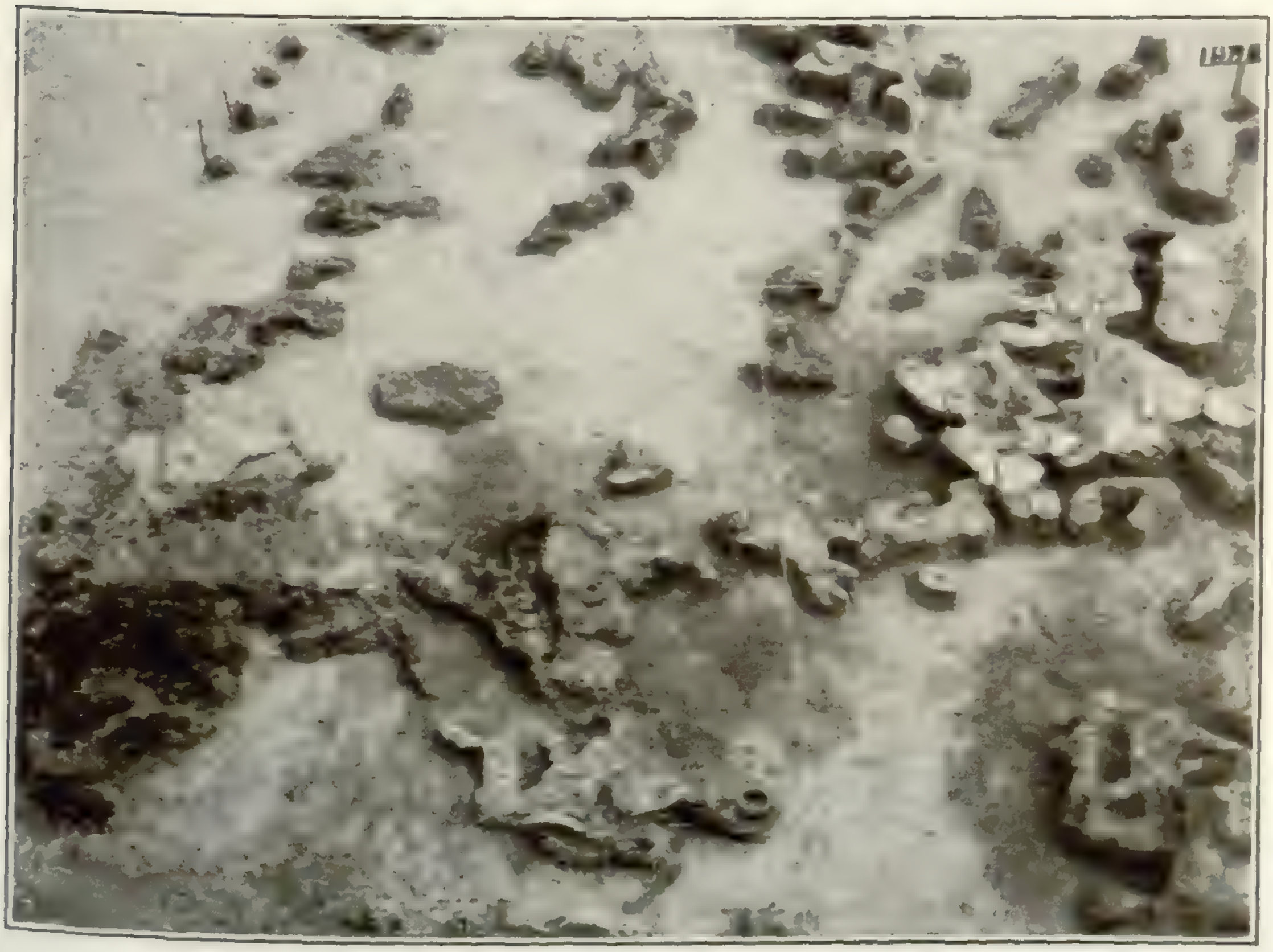

PLATE IV B

House Remains under edge of Mound Jo19

to one of the structures represented. The walls had been set in ditches and outlines of large round post molds set a few centimeters from each other were visible. (See Plate V A). The buildings had been square or rectangular. Large refuse pits were found within these outlines and some of them straddled the outlines and were definitely intrusive. A pottery handle possibly of a bean pot form and a few small sherds were found between the outlines. A small depressed outline 2.25 x 4 meters, of on aboriginal pit house lay a few meters to the west of the superimposed wall outlines. (See Plate V B). No definite post molds were found but fragments of charcoal were found along the edge of the structure indicating the position of small posts. Between the outlines of the large structures and the small depressed structure was a refuse pit containing large fragments of broken clay near the upper surface, presumably the broken remnants of a fireplace.

Over 60 refuse pits were found near the center of the village south of J°40 along the edge of the second terrace. (See Plate V B). These refuse pits were generally arranged in groups and each may have been near or in a house structure. However, the humus was black for such a considerable depth and the habitation level (20 to 30 centimeters) so close to the surface that traces of wall outlines were not discernible. The refuse pits were round with an average diameter of 1 meter, shallow (extending not over 30 to 40 centimeters below habitation level) and flat bottomed. A few were splayed at the base. The decayed contents were very dark indicating large amounts of vegetable matter. Animal bones on the other hand were very few in number and consisted mostly of deer bones and a few turkey bones. Fragments of pottery and artifacts were usually found scattered from top to base.

The habitation level was 20 to 30 centimeters deep on the second terrace but it appears to have been destroyed by erosion in its east extension, now the first terrace. Thus a part of the village has been eroded since aboriginal occupation. We are certain that the habitation level and second terrace did extend into what is now the first terrace. Three types of pottery ware

PLATE V A

Superimposed Outlines of Former Houses Close to Surface in Jv32

PLATE V B

Semi-subterranean House Impression and Refuse Pit in Jv32

are found on the house floor at the base of J°40, in the fill of J°40, in the refuse pits in the village and in the habitation layer. There are a small number of Herculaneum Cord Roughened pottery sherds, a preponderance of Imperial Plain pottery sherds from J°40 mound fill and a preponderance of Plattin Clay Tempered ware from both the village habitation layer and the refuse pits in the village. A percentage study of the ware is instructive.

Imperial Plain sherds were predominate from the mound fill. Of 651 sherds, 78% were Imperial Plain; 22% were Plattin Clay Tempered and Herculaneum Cord Roughened, but there was a thorough mixture of the three wares throughout the mound fill. From the trenches of J^{v}32, 1848 sherds were found. 17% of these sherds were Imperial Plain, 15% Herculaneum Cord Roughened and 68% were Plattin Clay Tempered sherds. There was no visible percentage differences of these wares from level to level in the 40 centimeter depth of village refuse. Of 1193 sherds found from the refuse pits, only 4% were Imperial Plain sherds, 9% were Herculaneum Cord Roughened sherds and 87% were Plattin Clay Tempered. Many of the Herculaneum Cord Roughened sherds from the village were limestone tempered. The small percentage of Imperial Plain sherds from the refuse pits compared to the village was puzzling, but when we realize the extremely acid nature of the refuse pits it is possible to explain this discrepancy. The shell tempering leached out more rapidly from the sherds from the refuse pits than from the village habitation levels. The thorough intermixture albeit reverse percentages of wares from both the mound fill and village trenches points toward occupancy by one group for both the mound and village sites. Add to this the similarity in size and shape of the house outlines from the base of the mound and the village, quantities of charred corn from both the mound and village site, the comparatively few animal bones from the village and house at the base of the mound indicating that hunting was secondary, and the construction of a mound over the burned remains of a deer indicating that animals may have had totemic significance, and we begin to realize that the village and the

mound were occupied by a single group or by two closely related groups.

An examination of artifacts from the village further substantiates our conclusions that we have an intensely agricultural group forming cultural tieups with those who constructed the mound. (See Plate VI B, includes also artifacts from Jc21). There is an extremely small percentage of chipped points which include broad stemmed knives and small isosceles projectiles. A stemless bowl pipe for use with a reed stem, a bent tubular pipe of Imperial Plain ware, a chipped hoe polished at the cutting edge through use, polished celts, biconcave discoidals, perforated shell hoes, a highly polished bone point with an eagle effigy carved at the base and other bone points were found in the village. Add to this the discovery of Imperial Plain pots with extended human burials in stone box graves just to the north of the mound and we have a fairly typical picture of a primitive agricultural community.

THE McCORMACK CEMETERY (LOCATION VI)
Jc21

Unfortunately we could not investigate the cemetery with stone box graves at the north end of Jv32 for it was in alfalfa, but we did locate a cemetery Jc21 two miles south of Jv32 on the right bank of the Plattin. Several rectangular stone box graves each containing a single extended skeleton associated with pottery, and an oval stone box containing a bundle burial were discovered. These graves seem to be highly similar to those dug up by Mr. Boyce's father alongside Jo40 and Jv32, therefore it is very probable that the peoples who were buried at Jc21 were of a very closely related component to those buried adjacent to Jv32 and Jo40.

The stone box graves lay very close to the surface so that there was only one grave that was unscathed. The remainder, of which there were ten, generally had the side slabs torn out or leveled by the plow. Three of the burials consisted of scattered human remains in the dark soil area. Pottery fragments and a complete water bottle next to a projectile point lay near two of

them. Two large upright rocks lay to the north of this. At the base of one of them was a nearly complete deep olla or jar with flaring rim and two loop handles. Presumably the rocks and bones had been gouged out by the plow.

None of the graves had stone covers but all were encased by vertical side and end slabs and the bottoms were lined with slabs also. All skeletons with one exception were extended with one skeleton to a stone box grave. The remaining box, oval in shape, contained a disarticulated skeleton with no grave furniture (J^{c}21-6). Complete small common bowls and one or two plate forms were buried at the head.[1]

In addition to the pots one individual had as grave furniture a red claystone pipe placed over the center of the stem (projecting stem variety), and a highly polished thin ax or spud of chipped flint with a ground flaring bit (J^{c}21-2). Another was accompanied near the pelvis region by the severed head of a second person, a flat section of chert roughly ladle shaped and two small ollas or jars buried at the head (J^{c}21-4). (See Plate VI A). Another burial had but one very small olla buried at the head (J^{c}21-11). All burials appear to have had pottery buried with them. In three instances the plow had neatly torn away the side slabs and the grave furniture leaving only the bottom slabs, fragments of pottery and a few bones in position (J^{c}21-5-8-10). The remainder of what were once graves were only dark patches of earth containing a few fragments of human bones.

The pottery ware was nearly entirely Imperial Plain and consisted of small ollas or jars with and without loop handles, a water bottle and a plate. There were a few Plattin Clay Tempered and Herculaneum Cord Roughened (limestone temper) sherds. The artifacts consisted of the claystone pipe, the thin ax, a polished chisel or small celt, a finely chipped stemless projectile point with a convex base, and a fragment of a finely chipped knife. (See Plate VI B which includes also artifacts from J^{o}40 and J^{v}32).

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[1]It is fortunate that we were able to work at this location and so conserve the few remaining graves that had not been completely destroyed by the plow.

PLATE VI A
Stone Box Grave in Cemetery Jc21

PLATE VI.B

PLATE VI B
Artifacts and Pottery from Jv32, Jo40 and Jc21
(For description see Plate XII B)

This cemetery seems to belong to the same cultural unit on the focus level as do Jv32 and Jo40 so that we are probably justified in considering its cultural content to be supplemental to the traits from Jv32 and Jo40.

Apparently a village site (Jv93) lies 50 meters to the southeast but it was under cultivation so we could not investigate it.

THE JENNI MOUND (LOCATION XI)
Jo60

The Jenni mound is 37 meters in length by 16 meters in width. The greatest depth of debris was found to be 1.60 meters. The mound lies at the northern extremity of a large level high terrace above the right bank of Plattin Creek.

Several test trenches dug at various intervals around the mound revealed very few pottery sherds and only occasional chips of chert indicating that there was no village in the immediate vicinity. The whole south end of the mound was disturbed so that no excavations were carried on at this point.

Evidences of a ditch with modern chinaware at the bottom of it were found near the north end of the mound. Furthermore, a long iron rod used as a probe was found in the mound fill near this ditch. Numerous pits dug by commercial excavators were found both on top and along the sides of the mound. Fortunately the diggers just missed a small oval stone box grave containing a few fragmentary bones of what had apparently been an infant burial. Below the mound structure lay a rectangular stone box grave with a bundle burial of an adult along the southeast edge and a few fragments of a bundle burial along the east edge on the original ground surface.

It was found that a large portion of the original surface of the northern part of the sub-mound area had been leveled before the mound had been erected. Two layers of dirt fill of different shades were found to have been used in constructing the mound. The lowest layer was much darker, probably entirely humus, placed beneath an upper layer which was lighter in

color. (See Plate VII A). This two-toned mound fill may have been purposely used in the mound construction.

Just west of the center of the axis of the mound the remains of a burned wooden rectangular structure were found at the base of the mound. Traces of charred vertical posts forming the wall of this structure were clearly visible, as well as a small round clay lined fireplace with a concave bottom near the center. (See Plate VII B). The posts were more or less completely intact indicating that the wall posts were 10 to 15 centimeters in diameter and had been placed so that they touched each other, much in the manner of a palisade. They had been inserted at a depth of 20 to 25 centimeters but no apparent ditch could be found into which they had been placed so that the posts appear to have been driven into the ground. The bottoms were slightly rounded but not pointed or wedge shaped. The long axis base of the house was parallel to the long axis of the mound.

Between the northern end of this structure and the center just west of the longitudinal axis of the house was found an extended burial, located 15 - 20 centimeters below the floor. This burial was without a head and almost entirely calcined. Below the bones were remnants of a coarse matting with twined weaving possibly of shredded bark. One small section of a much more finely woven twined material lay between a fragment of the left tibia and the twined matting and had been apparently a portion of the clothing of the individual. As there was no evidence of burning beneath the skeleton it is believed that the structure had been erected over the deceased and then burned, and this burned the burial. A deep and narrow pit filled with dark disintegrated vegetable matter lay below the mound base 2.5 meters east of the northern half of the house structure.

It is noteworthy that less than a dozen sherds and no artifacts were found in the mound fill and in the pits excavated around the mound. These few were Imperial Plain sherds. On one of them was a duck's bill effigy from an effigy flange bowl. It had a black slip. Another sherd with a black slip belonged

PLATE VII A
A Profile View of Mound Jo60

PLATE VII B
View of Ceremonial Structure in Jo60

to a water bottle. Two sherds had a red slip and appear to be fragments of a water bottle.

THE HERRELL VILLAGE (LOCATION XII)
Jv55

Test trenches are now being laid in this site. Up to November 1st three trenches were cut in that portion of the village that lies on a low second terrace[1] along the western half of the village. It was found that the habitation layer had been partly destroyed by the plow but deeper portions of the habitation zone and particularly numerous and small pits were largely undisturbed.

Shallow pits were approximately 1 meter in diameter containing several layers of broken pottery fragments intercalated with basin shaped clay layers. These pits were not over 50 centimeters deep or 35 to 40 centimeters below the original habitation level. They were usually close to small oval baked clay or large irregular fireplaces. A few of the pits had very large complete common bowls in them. (See Plate VIII A).

Where not completely broken up by the plow it was quite apparent that the rims of the pits lay on the same level as the fireplaces. Therefore, these pits were apparently used for cooking purposes. Animal bone and mussel shell fragments were found in a few of them showing that these were also used as refuse pits. Several large limestone blocks were found under one of them. The bottoms of most of these shallow pits were lined with clay.

Just to the northeast of this pit we encountered a long rectangular depression in which were found over 4000 pottery sherds. Indeed it was the rectangular outline in the ground produced by the disposition of these sherds that caused us to notice the pit outline. The southeast end of this pit was convex, was heavily burned and contained no sherds.

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[1]The eastern half of this site lies along a low flat ridge above the second terrace and has been named Zone III. It is hoped that the owner will allow us to investigate here.

A definite wall outline below the periphery proved that this was the remnants of a house with a depressed floor. A human skeleton partly destroyed by the plow was found only 15 centimeters from the surface a few meters north of the rectangular house pit. It lay extended on its back and was a very short male of nearly middle age. A very small water bottle and a small common bowl with loop handles were found at the head. A portion of a rim was found at the head indicating that probably a flaring rimmed olla or jar was also buried there. Another extended burial of an adolescent next to the burial of a child with a small olla or jar at the head lay under a large limestone block which was 1 meter on a side. Several textile-impressed potsherds were found nearby.

Large deep conical flaring mouthed ollas or jars, water bottles, ollas with narrow necks, large seed bowls, very large shallow bowls with and without textile impressions, plate forms with etched designs on the upper surface, disc shell beads, columella of Busycon shells, perforated shell hoes, polished celts with flaring bits, unperforated bone needles, small isosceles triangular projectile points and large circular grinding stones have been found thus far in the village debris. The ware is Imperial Plain and is often slipped with a red or orange clay. A few Crystal City Cord Roughened sherds have also been found. (See Plate VIII B).

Animal bone remains found in the village include mainly the deer although there are a few bird bones.[1]

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[1]As this publication goes to press we must report the discovery of several mastodon bones from cooking basins and refuse pits found within a large rectangular house supported by four center posts. (See Plate IX A). There is no indication that they were used for implements for they show no evidence of having been used or worked. As they were found with village refuse, but not with human burials or other evidence of ceremony they do not appear to be ceremonial objects.

According to Dr. E. Olson, our consultant on vertebrate paleontology, one or two of the extinct mastodon bones are mineralized Therefore, the question of contemporaneity of these people and the mastodon will remain undecided until we have more evidence. There is also the possibility that the bones were dragged over from the bone bed Jm2 out of curiosity.

We have recently located two pockets of Herculaneum ware without Imperial sherd associations below the lowest occupation level at Jv55.

PLATE VIII A
Large Cooking Pot in Pit in Village Jv55

PLATE VIII B
Pottery and other Artifacts from Village Jv55
(For description see Plate XIII)

More about this important site will be given in our next published report as investigations are continued here.

IV. ROCK SHELTERS

The analysis of rock shelters presents a fundamentally different problem than do the open sites. Only small family groups could occupy them at a time thus remains are usually found in small pockets. The chances of obtaining stratigraphy are much greater in rock shelters than in open sites because the rock shelters afford permanent protection to many different groups of people over a period of time probably equal to the time that man has been in the region in some instances. Most of the rock shelters that we have investigated have stratified deposits.

GROUP OF SMALL ROCK SHELTERS IN SIDE OF MISSISSIPPI RIVER BLUFF (LOCATION II)

$J^{s}1$, $J^{s}2$, $J^{s}3$

There are three rock shelters lying not more than 200 meters distant from each other in the sides of the bluff of the Mississippi River.

The most northerly of the group, $J^{s}2$ is a very small cavity only 2 meters across the face and less than 2.5 meters deep. A temporary irregular fireplace was found near the surface. Twenty centimeters below this was a round fireplace consisting of ash and burned clay. There were a few sherds, an imitation bear canine made from the columella of a Busycon shell and a small pebble hammerstone around the fireplace. The pottery was Herculaneum Cord Roughened but there were a few Imperial Plain sherds.

$J^{s}1$ a few meters south of $J^{s}2$ is 14 meters across and approximately 8 meters deep. It contained a fireplace 80 centimeters deep, very small and irregular. Pottery fragments, very few artifacts, mussel shells and animal bones were found in the original shelter floor at a depth of 140 centimeters.

A few Imperial Plain and Crystal City Cord Roughened sherds were mixed with a much larger number of Herculaneum Cord Roughened sherds near the surface. Herculaneum Cord Roughened sherds were found down to the rock floor. There were no Imperial Plain or Crystal City Cord Roughened sherds below 30 centimeters depth. The Herculaneum Cord Roughened sherds found near the bottom definitely had much more irregular sized tempering than the sherds from nearer the surface but could not be classed as Herculaneum Reddish Buff or Rouggly Uneven Grit. Some of the sherds appeared to have clay tempering also. Not one complete artifact was found.

Js3 is 75 meters south of Js1. It is very small, being only 6 meters across the mouth and is approximately 6 meters deep. The rock floor rises abruptly and appears above a silt fill at the back of the shelter. There were no signs of aboriginal occupation on the surface. A definite hobo level was distinguishable with tin can refuse, iron nails and modern wood to a depth of 15 to 20 centimeters.

At a depth of 30 - 40 centimeters in the center of the silt fill was found a straight line of disintegrated post bottoms across the width of the shelter. These appeared to have served as a support for a wooden platform or bench the back end of which rested on the upward sloping rock at the rear of the shelter. From 30 to 60 centimeters depth an intensive occupation layer was found in front of these post remnants containing considerable quantities of ash, mussel shells, sherds and worked artifacts. No fireplace with clearly defined outlines was found but the ash content left no doubt that fires had been kindled in front of the platform.

The pottery on these middle occupation levels was a mixture of Herculaneum Cord Roughened and Imperial Plain ware. Of 88 sherds, 46 were Herculaneum Cord Roughened, which included 18 limestone tempered and 5 mixed limestone and shell tempered sherds, 19 were Plattin Clay Tempered, 20 were Imperial Plain, and 3 were St. Jo Polish Plain.

In the three 10 centimeter levels below this occupation containing the post molds there were no Imperial Plain sherds. Of 20 sherds, 7 were Herculaneum Cord Roughened, of which 4 were limestone tempered, 12 were Plattin Clay Tempered and 1 was St. Jo Polish Plain.

Ash also occurred at these levels as well as a crudely chipped adze made of flint, an awl made from a large sliver of bone and an antler point with evidence of having been polished through use at the tapering end. Fragments of chipped projectile points were found under a large limestone block that had fallen from the shelter roof. Considerable numbers of animal bones indicate a limited hunting economy. Represented are mussels, birds, turtle, rabbit, possibly the bear and the deer.

Occupation must have taken place in these small shelters during the time that they were being filled with wind blown silt. As far as this rock shelter is concerned shell tempered Imperial ware represents a later ware than Plattin Clay Tempered and grit tempered Herculaneum Cord Roughened continued through all levels of occupation. It is significant also to note that the numbers of sherds increased the more superficial were the deposits.

HIDDEN VALLEY ROCK SHELTER (LOCATION III)
Js7

The Hidden Valley Rock Shelter is located on a small tributary to the Joachim. The shelter sets back from this tributary and forms the head of a small wet weather branch. The shelter is large and gives the appearance of an amphitheatre. The mouth of the shelter faces east. It is approximately 35 meters across the mouth and is 15 meters deep. At the south end of the shelter there are several large stone blocks on the silt fill floor weighing several tons apiece. On one of these is a carving of a "thunderbird." These fell from the shelter roof. A few smaller blocks lie on the surface at the north end of the shelter. There were few blocks visible near the center of the shelter in spite of the fact that the shelter ceiling was very much higher at this point than at either end of the shelter.

The surface of the shelter to a depth of 15 centimeters was littered with rusty tin cans, crockery, nails and fireplaces left by modern campers.

After laying out our two meter grid system we marked out the deposits in 10 centimeter vertical layers leaving steps at intermittent squares for profile study. Expansions were often carried out on one level to expose fireplace outlines. Soon after excavations were started a stain was noted on the floor of the excavations at the north end of the shelter indicating a possible bank level of an ancient gully along the shelter edge that had been subsequently covered with silt. This discovery forced us to alter our excavational procedure which then consisted of a trench excavated to the original rock floor running across the shelter mouth approximately under the overhang. We were, therefore, able to photograph visible stratification lines in our vertical profiles.

Investigations on this large trench have been completed. This winter we shall work out the remainder of the deposits between the rear of the shelter and the sub-overhang trench.

The silt fill of the shelter had accumulated largely as a result of surface water erosion along high talus banks flanking the two ends and partly as a result of disintegration of the rock shelter which was hollowed out of Saint Peter sandstone.

As we excavated the sub-overhang trench it became increasingly apparent that there had been two shelter fills. Along the northwest and southwest edges of the shelter were deposits showing little organic content with predominant silt fill. In all of the center of the shelter and the northeast and southwest ends of the shelter the silt fill was a much darker color. As a result a saucer shaped outline tapering to a restricted area where the intermittent underground stream now issues from the shelter is visible in our photographs (See Plate IX B). The dark area with humus content extends to the rock floor where the stream leaves the shelter and is much more shallow at the south end. The edges of the old gully bank are visible on the vertical profile at A, B and on the horizontal profile C.

PLATE IX A

Sherd Lined Concave Pit Containing Bones of the Mastodon in Village Jv55

PLATE IX B

View of Vertical Profile in Rock Shelter Js7 Showing Outline of Old Gully Fill

in the isometric drawing (See Plate X A). The first clue indicating that we had an old gully bank to consider was given by the presence of stone artifacts without pottery accompanying them at the floor area marked D in the old silt area along the northwest edge of the shelter. The change in excavational technique has since borne out our theory.

When did the erosion period that cleaned out the earlier silt fill occur ? It may have taken place when there was far greater rainfall than at the present time. This erosion period might possibly prove to tie in with the post glacial pluviation mention by Dr. E. Antevs as occuring some 3000 years ago.[1]

The oldest occupations of this rock shelter contain very long projectile points with expanding stems, elongated S shaped edges and concave bases, a long curved blade and large disc scrapers (Plate X B) with a single flaked surface on one face found in loose sand that covered the original sand floor of the shelter before silt had begun to fill the shelter.

Crushed charcoal and soft animal bones too fragmentary to be identified were also found. These lay on the sand floor except in the area where the underground stream issues from the rock shelter under the overhang where objects of several occupations and differing ages are found mixed together, and in localized pockets in the center of the shelter where the later shelter fill penetrates to the original sand floor. The implements are invariably stained by iron precipitate leached out from the layer above them and re-deposited. All are more or less dehydrated in spite of the moist conditions in which they were found.

At more shallow levels within and along the northeast and southwest flanks of the shelter in the first silt fill were found two small circular fireplaces consisting of charcoal. The one at the south end of the shelter lay at a considerable depth (See Plate XI A), below large fallen blocks from the shelter roof. No animal bones or stone implements were found near this fireplace. The other fireplace at the northwest end had stone

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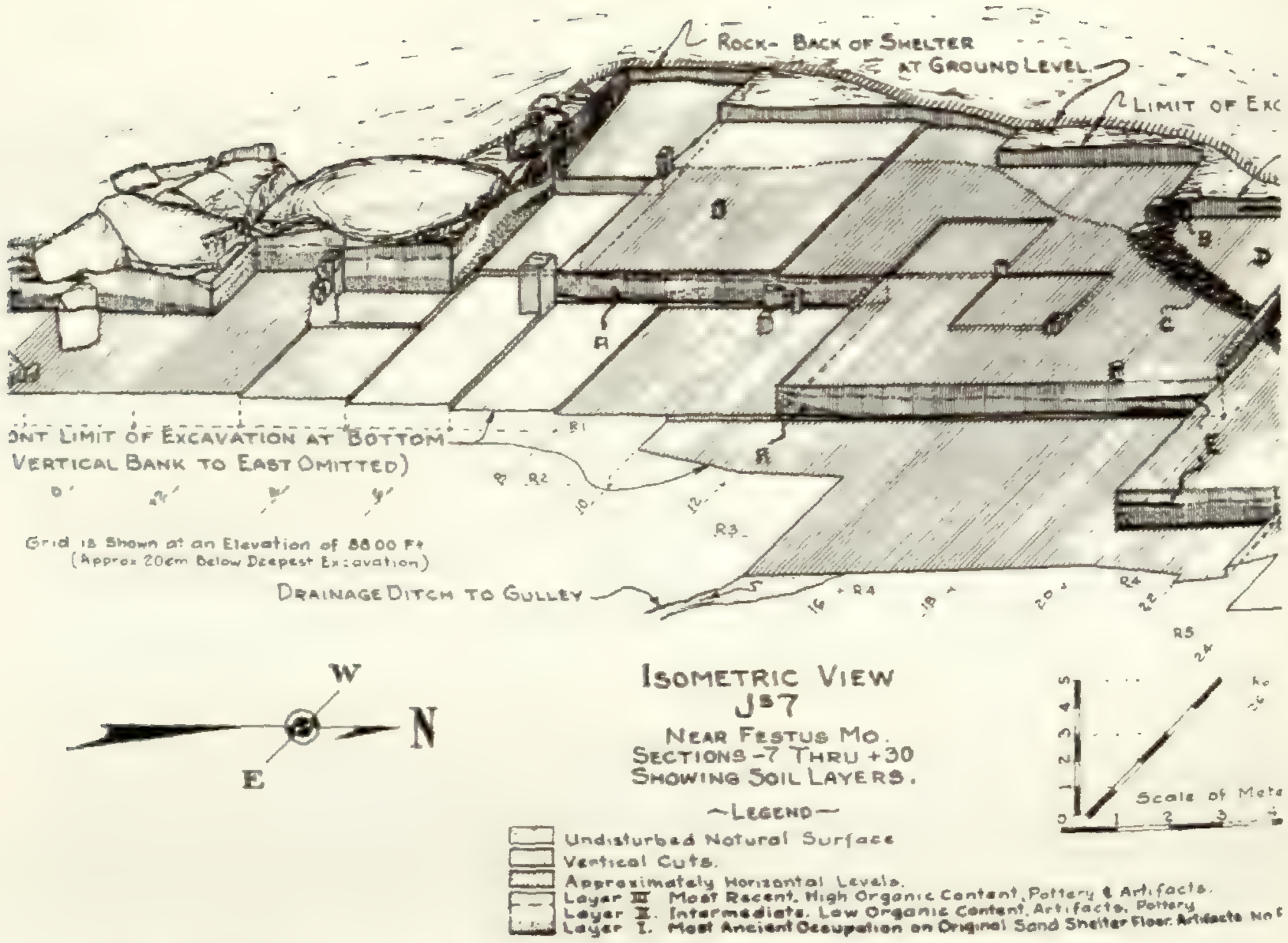
[1]Antevs, E. "The Archaeology of Pleistocene Lake Mohave," *Southwest Museum Papers,* No. 11, p. 48.



ISOMETRIC VIEW
Js7

NEAR FESTUS MO.
SECTIONS -7 THRU +30
SHOWING SOIL LAYERS.

—LEGEND—

- Undisturbed Natural Surface
- Vertical Cuts.
- Approximately Horizontal Levels.
- Layer III Most Recent. High Organic Content, Pottery & Artifacts.
- Layer II. Intermediate. Low Organic Content, Artifacts, Pottery
- Layer I. Most Ancient Occupation on Original Sand Shelter Floor. Artifacts No

PLATE X A
Isometeric View of Excavations to Date in Rock Shelter Js7

PLATE X B
Artifacts of Earliest Group that Occupied Rock Shelter Js7

implements scattered around it but there was no pottery except at B and C in Plate XA, which is the contact zone between the early and later silt fills. The two latter occupations must have been at a later interval of time than those implements that were found on the original shelter floor but were located from the original silt fill.

One very large irregular fireplace at the northwest end of the shelter (See E of Plate X A) and several other smaller areas containing pockets of chipped implements were found at depths of from 60 to 100 centimeters (20 to 40 inches) under the overhang in the lowest levels of the later silt fill. With these chipped implements was a very small number of sherds. Both the implements and the sherds were stained by iron precipitate leached out from superimposed deposits. Animal bone remains were very small and fragmentary. An antler tine was found in the fireplace and this was definitely mineralized. Typical stone implements are concave based projectile points similar to those from the Signal Butte I Nebraska site and long side notched projectile points typical of the Black Sand component from Illinois (See Plate XI B). The few sherds occurring were of Hidden Valley Crushed Quartz ware.

Evidences of more recent occupations have been found almost over the entire shelter. In certain areas such as the north extremity of the shelter, these occupations lie close to the surface but throughout most of the shelter area they are often found at considerable depths such as in the area just north of the large boulders, and in pockets clear down to the original sand floor at the center of the shelter. Under the center of the shelter overhang they are found down to the original sand floor due to the stream erosion and appear to be in secondary position, but a few meters north of this point and also just north of the large boulders at the south end of the shelter the more recent occupations extend down approximately 60-75 centimeters (25-30 inches). However, it appears that at no time in the history of the occupations of the shelter was the upper surface completely level. It is not uncommon along the boundary of the

PLATE XI A
Small Round Circular Fireplace under Large Rocks in Rock Shelter Js7

PLATE X. B

PLATE XI B
Artifacts in Early Woodland Group that Occupied Rock Shelter Js7

recent and old silt fills to find groups of sherds and artifacts next to and at the same depth as pockets of much older implements with no pottery or a very small amount of it.

Fireplaces with these more recent occupations vary. The older fireplaces are simply large irregular masses of mashed charcoal and charcoal stains in the silt fill. The more recent fireplaces seem to have been small oval or circular burned clay formations. Several of these have been noted close to the surface and large irregular fireplaces have been burned to an average depth of 60 centimeters (25 inches) just north of the large boulders at the south end of the surface and 20 to 30 centimeters depth at the north end. The erosive power of the intermittent stream seems to have at least partly broken up fireplace formations at the center of the shelter and under the overhang where the stream issues from the shelter. Pottery fragments and artifacts are usually found around these fireplaces but not always. Occasionally they are found at considerable distances from such indication of more or less permanent occupancy.

In contradistinction to the earliest and the middle occupations animal bones are quite plentiful with these occupations and include predominantly deer, turtle, fish and birds, and groundhog.

A percentage study of pottery types has revealed a very interesting situation. Imperial Plain sherds and Herculaneum Cord Roughened sherds are found mixed with a dominance of Herculaneum Cord Roughened from the deepest levels to the surface of the area just north of the large boulders. With these sherds are short broad stemmed points and small isosceles triangular projectile points coarsely chipped. On the other hand the lower levels that have been excavated just north of the center of the shelter thus far show a marked predominance of Imperial Plain sherds near the surface, whereas at deeper levels Herculaneum Cord Roughened sherds are predominant. Of 72 sherds found to 20 centimeters below the surface in this localized area, 50 were Imperial Plain and 22 Herculaneum Cord Roughened. Of 59 sherds found from 20 to 40 centimeters deep only 11 were Imperial Plain but 48 were Herculaneum Cord Rough-

ened. There was only one fragment of a chipped implement at the higher occupation. No small coarsely chipped isosceles projectile points were found in this area. These figures may be rather significant and seem to indicate a more or less constant occupation of a recent prehistoric group just north of the large boulders and two more or less recent occupations just north of the center of the shelter, the earlier Woodland with Mississippi influence and later a Mississippi with Woodland influence group.

A square nail, an Imperial Plain sherd and a short broad projectile point were found at a depth of 45 centimeters in the area where the intermittent stream issues from under the overhang, but in this area one would tend to expect a mixture of ancient and modern, being in the path of the stream. The crockery, tin can fragments, Civil War bullet and button were all found within fireplaces very close to the surface (15 centimeters) and without pottery so can scarcely be considered evidence of Indian contacts with the early settlers.

ROUGGLY ROCK SHELTER (LOCATION VIII)
Js30

The Rouggly rock shelter is under a bluff which projects over a rock platform on which there are silt deposits of only a few centimeters depth. A narrow talus slope in front of this rock platform slopes down into the Plattin Creek and revealed evidence of occupation up to a depth of approximately 75 centimeters (30 inches). The entrance faces south. There were two depressed oval fireplaces of mixed clay and silt fill close to the surface. Pottery fragments and artifacts were found from the surface to sterile bottom which consisted of a mixture of rock outcrop and gravel deposited by the stream.

Herculaneum Cord Roughened sherds of which there were 699, were found distributed evenly from the surface downward. Twenty-five of these sherds were tempered with limestone and these were also found evenly distributed from the surface to the base of the deposits. Only 18 Imperial Plain sherds were discovered and these were uniformly close to the surface. There were also a few Plattin Clay Tempered sherds

(32). These were mixed with the Herculaneum Cord Roughened sherds and were found at levels deeper than the Imperial Plain sherds. Short broad projectile points and narrower points with contracting stems were found. A small pocket with sherds and a point was found close to the perpendicular side of the rock platform and near the bottom of the cultural deposits. The sherds comprised a large portion of a small thick walled pot. They were of the Rouggly Uneven Grit type of ware and the point was similar to the projectile points notched near the base and found with the Black Sand component in Illinois.

Percentage studies of the pottery reveal a convincing change in proportions of ware types from the deep levels to the surface of Js3, Js7 and Js30. Imperial Plain ware is completely absent in the lower levels and the Plattin Clay Tempered ware is found mixed with Herculaneum Cord Roughened at deeper levels than the Imperial Plain, giving possibility as at Js3 that the Plattin Clay Tempered ware is older in some of the rock shelters than the Imperial Plain.[1]

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[1]As this publication goes to press we must report highly eroded fragments of Imperial sherds with Herculaneum sherds at the base of later rock shelter fill at Js7 in secondary position in the center of a trough shaped gully area at depths of 125 centimeters or over four feet. Our exhaustive study of this rock shelter forces us to reconsider the relative age of the Imperial ware, some of which must be old although probably not as old as the intact middle occupation in which were found the Hidden Valley Crushed Quartz ware together with long side notched points and concave based points.

V. TRAIT ANALYSIS CHART

Location I

Site	Stratification and Components	Traits
Jv5	— W. M. I. Woodland Mississippi Influence	—Small temporary fireplaces; no house outlines but probably small temporary structures; A1 and A2 ware; grooved axes of hematite; chert nodule hammerstones; long and short stemmed points; medium to thin regular flake scars; hunting economy and short occupations indicated by small number of animal bones; flint flaking activities; more than one component ?
Jo1	— 1. W. (M.I?) — 2. W. (M.I?)	—1. Flat rectangular formation of lime- —stone covering partly articulated human burials; A1 and A2 ware; long and short stemmed points; also isosceles triangular p.p's; no pottery or artifacts under mound, therefore mound constructed during village occupation. 2. Submound pit extended burial with finely chipped stemmed point.
Jo2	— W.	—Burial complex indeterminate but included associated rock formation (disturbed); A1, A2 ware; one amphora pottery form; pot loop handle; grinding stone and pestle; stemmed p.p.'s; mound constructed at same time as part of village occupation.
Jo35	— W. M. I.	—Partly articulated skeletons near mussel shells flanked on N and S by large rock formations and covered with mound fill; over burial fill and between rock formations was rectangular ceremonial structure with fireplace near center showing evidence of intense fires; A1, A2, B1 wares; 2 pot shapes, amphora and common bowl, bean pot handle, indented

Site	Stratification and Components	Traits
		pottery disc, polished celt and chisel celt; stemmed p.p.'s; winged drills; mound constructed same time as part of village occupation.
	Location II.	
Js3	— 1. W. M. I.	—1. Number of mussel shells; ash fill;
	— 2. W. (M.I?)	—charred wooden supports for bench; A1,
	— 3. W.	—B1, B2 wares; 3 pot shapes, amphora, common bowl and water bottle, fine grained smoothing or polishing stone; chipped adze; stemmed points with coarse to fine flake scars; slender bone sliver awls, antler flakers. 2. Majority A1 ware; small number of B1 sherds; stemmed p.p's. 3. Lowest 3 levels contained only a few A1 sherds.
	Location III.	
Js7	— 1A W. M. I.	—1A. Preponderance of A1 over B1 sherds;
	— 1B M. W. I.	—more than one pot shape, amphora and
	— 2A W. M. I.	—olla or jar; stemmed points; small isos-
	— 2B W. M. I.	—celes p.p. 1B. Preponderance of B1 over
	— 3 W	—A1 sherds; more than one pot shape, am-
	— 4 E. H. C. Early Hunter Culture	—phora and olla or jar, fine flake scars. 2A. Large fireplace, preponderance of A1 over B1 sherds; stemmed p.p.'s. 2B. Preponderance of A1 over B1 sherds; stemmed points. 3. Large fireplace; A3 ware; great preponderance of flint work over number of sherds; concave based and side notched near base forms; mineralized animal bones. 4. Small circular fireplaces; no pottery; long p.p.'s with expanding concave base and S shaped profile, large round scrapers (with single flake backs) also bent blade.
	Location IV.	
Jv321	- M. (W. I.?)	—Rectangular house outlines with large posts placed in ditches around house and rounded corners built over each

Site	Stratification and Components	Traits
		other; two or three small fireplaces together in houses; two or three refuse pits in floor of house (plus others that were intrusive); quantity of charred corn and sherds including bean pot handle on floor; small semi-subterranean rectangular house near large superimposed house outlines; 60 refuse pits investigated; these pits often concentrated in restricted areas indicating possibly presence of former house structures; usually very black fills indicating large amount of decayed organic remains; C ware predominates in both trenches in village and refuse pits; 3 pot shapes for C ware; some B1 and A1 ware thoroughly mixed with C ware; stemless pipe; bent tubular pipe; medium to fine flake scars on flint implements; small isosceles p.p; stemmed points; expanding base drill; chipped hoe of flint; chipped polished implements relatively rare; polished celt; polished biconcave discoidal; effigy pointed bone; highly polished bone points; intensive agriculture indicated by dark refuse pit fills; large grained charred corn; perforated shell hoe; charred acorns; few animal bones attesting to limited hunting activities.
Jo40— M. (W.I?)		—Once steep sided small ceremonial mound in bottomland next to village site (Jv32) covering deep narrow pit and disintegrated bark containing pottery with bony ash and bones indentifiable as deer; rectangular house below edge of mound containing wattlework; chisel pointed poles pushed directly into the ground; quantities of charred corn and 3 bowls, one being crushed (grade B1 ware); predominance of B1 ware; A1 and C wares present also; at least 5 pot shapes; textile marked thick sherds; etching or in-

Site	Stratification and Components	Traits
		cising; notched small isosceles p.p.'s; burial component near Jv32 and Jo40 not investigated but extended skeletons in stone box graves reported with grave accompaniments.

Location V.

Jo57— 1A. W.?
— 1B. M.?
— 2. W.?

—1A. Two intrusive burials; an ossuary
—with decapitated craniums; a tightly
—flexed burial covered with rocks.

1B. Two intrusive extended burials sunk below base of mound in separate pits in a trench the post-burial fill for which was carried up from bottomlands; one of these burials had a bone hair ornament at the head and a rectangular pavement of limestone slabs beneath it.

2. Primary mound consisted of three angular flint platforms apparently in animal effigy outlines and covered over with rock mantle and dirt covering; grooved ax; stemmed p.p.'s; no pottery; center of mound destroyed by commercial pittings. No village in mound vicinity.

Location VI.

Jc21— M.

—Stone box graves with single extended skeletons on back; pots; a red claystone pipe, bowl shaped mounted on top of a stem; a finely chipped p.p. and a highly polished spud buried at head of individuals; pots most common; one skeleton and decapitated head of another individual over central ventral section; burials in cemetery adjacent to village; 3 pot shapes including olla or jar, water bottle and plate forms; one stone box grave, oval in shape, with disarticulated skeleton and no grave furniture; B_1 ware; a few A_1 and C sherds. It is estimated that at least one half of graves had been destroyed by plow; village

Site	Stratification and Components	Traits
		with surface sherds a few hundred yards away but separate from cemetery we were unable to investigate because the field was in alfalfa.

Location VII.

Jo19— W. M. —Low mound with residual flint mantle (north half destroyed by commercial pittings). Near center a small rock vault wall (fortunately only a corner disturbed) of large flint fragments superimposed directly on rectangular platforms of flat limestone slabs on which were several fragmentary bundle burials, the vault wall covering a portion of these burials. Some sort of crude wooden superstructure erected over dirt fill inside vault walls oval in shape. Intense fires kindled in this structure which was burnt itself, the fill being burnt all the way down to the burials which were partly charred; deep narrow pit fill with dark humus under rectangular platform; a few sherds all of grade B1 ware including a perforated pottery disc; a red painted sherd; red slip tetrapod pot reported from commercial digs from here. No accompanying village site.

Location VIII.

Js30— 1. W. M. I. —1. Preponderance of A1 ware over B1
— 2A. W. —ware; some C ware; 3 pot shapes; per-
— 2B. W. —forated disc of thick pottery; polished ax; very small stemmed p.p.'s.
2A All A1 ware in lowest levels; stemmed p.p.'s. 2B. Thick small pot of A4 ware with point side notched near base in occupation pocket.

Location IX.

Jv62— W. —Extensive but thin occupation layer containing barely discernible temporary fire-

Site	Stratification and Components	Traits
		places; no house outlines but probably small temporary structures were used. All A1 ware, but few sherds; only one pot shape distinguishable; oval flint knife; stemmed p.p.'s.
	Location XI.	
Jo60— M.		—Large elongated mound with indications that it once had steep sides, (south end not investigated because of extensive commercial pittings); two-color fill in north half of mound; center contained remains of burned rectangular ceremonial structure with a small oval clay fireplace and rounded ends near center; beneath floor of structure at north end was an extended skeleton almost completely cremated as a result of burning of superimposed structure. Portions of woven grass or bast clothing and burial mantle preserved; very few sherds; all B1 ware and duck bill effigy flange; two stone box graves below mound's east edge. No village site could be located in vicinity.
	Location XII.	
Jv551 - M.		—Low mound erected over shallow pit containing red ocher and compact clay over which are human bones.[2] Extended burials in shallow pits lined[3] or unlined with large sherds; burials with or without grave furniture, grave furniture mainly small pots; burials in village; sherd and clay lined cooking pits or large bowls adjacent to small concave baked clay fireplaces or irregular fireplaces; animal and shell refuse often in cooking pots or sherd lined pits; small houses with shallow depressed floors and ditches below the boundary in which were vertical wall posts spaced a few centimeters apart; also large nearly square houses with center supporting posts; B1 most preponderant, but some

Site	Stratification and Components	Traits
		B_3 ware; B_2 ware is present, but rare; sometimes red slip on B_1 pottery; several pot shapes, including ollas or jars, common bowls, deep conical bowls, shallow bowls, effigy flange bowls, water bottle forms and plates; etched designs on plate rim upper surfaces; large bowls frequently textile imprinted; several different textile weaves noted; flaring bitted celts, small isosceles projectile points with and without notching; finely chipped straight stemmed projectile points; expanded base drill; long points of deer bones; short awls of deer ulnae; very fine needles without perforation made from bone slivers, flattened bones; chisel shaped smoothed bones; large disc shaped flat round limestone grinding stones; small clay pottery trowels; large mushroom shaped stone trowels; small shell beads; crinoid stem beads; perforated shell hoes; columella of Busycon shells; pitted sandstone drill holder; sandstone arrowshaft straighteners; evidences of small grained charred corn.

In order to facilitate analysis of the trait complexes that we have given in our descriptions of the locations investgiated, a chart of traits from locations, sites and components is given below. Irregular hammerstones of igneous rock or flint concretions, pitted or unpitted have been disregarded for these do not seem to have cultural significance.

[1]These sites have not yet been completely investigated.
[2]After G. Fowke's "Mound and Salt Springs at Kimmswick, Mo." *Bureau of American Ethnology Annual Report* No. 44, pp. 487-88.
[3]After D. I. Bushnell's "Archaeological Investigation in Ste. Genevieve County, Missouri," *Proceedings of United States National Museum*, vol. 46, p. 656. Mr. Bushnell sees similar modes of burial from the vicinity of Nashville, Tenn.

There are some resemblances, particularly in pottery, between Jv55 and some components in the Tennessee-Cumberland region, according to Mr. John Bennett, who is studying this latter material in connection with the University of Chicago's investigation of the Kincaid site on the Ohio River in southern Illinois. See also footnote [3] on page 217.

VI. CULTURAL RECONSTRUCTIONS AND AFFILIATIONS

The Woodland Pattern sites were indicated mainly by the following traits: Herculaneum Cord Roughened grit tempered pottery, one pottery shape, predominance of coarsely chipped stemmed projectile points, no evidence of agriculture and a lack of burial goods with bodies flexed or partly articulated. The Mississippi Pattern sites were indicated by Imperial Plain shell tempered sherds, comparatively small numbers of flint projectile points, small well-chipped isosceles triangular projectile points, polished celts, extended bodies usually with grave furniture and evidence of extensive agriculture.

A third Pattern is represented by the discovery of the long projectile points and curved blade without pottery associations from the lowest levels at the Hidden Valley rock shelter. It is too early to define this pattern clearly but pottery is scarce if present at all. It appears to have been entirely a hunting manifestation and is probably very old. Typologically the artifacts are by no means crude so that the pattern is in all probability post glacial but the conditions under which they are found reflect considerable age.

Evidences of three or four phases of the Woodland Pattern have been definitely discovered. Two of these are represented at the Pittsburgh Landing site and in the middle occupations at the Hidden Valley shelter. A third is represented at the St. Jo mound and village.

All of the objects from the Pittsburgh Landing village site indicate a Woodland group that had not come into contact with Mississippi groups. There were good indications that much of the original habitation level had eroded away. Only Herculaneum Cord Roughened pottery was found next to small irregular fireplaces. A crude flat pottery disc with a perforation for holding a drill, contracting stemmed projectile points, oval flint knives and a thin limestone ax with flaring bit complete our cultural inventory. This component certainly be-

longs to an early phase of the Woodland Pattern but we have not yet sufficient traits to assign a name to it either on the aspect or phasic level.

The same applies to the middle component at the Hidden Valley shelter where stemmed and stemless projectile points notched near the base and concave based points have been found with large irregular fireplaces and Hidden Valley Crushed Quartz ware. This component belongs to a different phase than the Pittsburgh village component, and may also be of considerable age. The area containing the point notched near the base and the Rouggly Uneven Grit ware from the Rouggly shelter may prove to belong to the same phase or to a different phase, but until there is more information we cannot assign a descriptive term on the phasic level. The effigy rock platforms, intrusive flexed Woodland burial and ossuary at the Govro mound are Woodland and appear to be ancient, but we cannot hook up with the early Woodland Manifestations.

More recent Woodland occupations with Middle Mississippi influence are represented at the St. Jo mound and village location. We have named it the Festus focus. Characteristic traits of this focus are small coarsely chipped isosceles projectile points, stemmed projectile points, expanded base drills, coarsely chipped adzes[1], grooved axes of hematite, hollowed mortar stones with pestles, burned clay discs with indentations showing use as possible drill holders, fine grained chisel celts, Herculaneum Cord Roughened ware with finger pinched marks below vertical lips and cord wrapped stick impressions on the inside of the lip, a small amount of Imperial Plain ware and partly articulated human burials surrounded or covered with limestone slabs within a mound. Occupation of the area surrounding groups of these small mounds apparently took place during the construction of the mounds. Mussel shells on the same level as the burials, human bones scattered in the mound fill, burials immersed in ash and small temporary ceremonial structures are also determinants of the Festus focus. (See Plate XII A).

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[1]From Js3.

The Middle Mississippi Phase is represented at the Boyce mound and village, the McCormack cemetery, the Jenni mound and the Herrell mound and village. Middle Mississippi traits are several characteristic pottery shapes, two pottery wares, limited use of projectile points, awl sharpeners and houses with rectangular floor outlines.

There are indications that the Boyce mound and village and the McCormack cemetery belong to one aspect and the Herrell mound and village belong to a second distinct aspect. However, it is necessary to conduct more investigations before we can clearly define them. For the present we will define the former as belonging to the Plattin focus and the latter as belonging to the Kimmswick focus. Surface examinations of several sites indicate that there are several locations containing the Plattin focus and several locations containing the Kimmswick focus from this and surrounding counties.

The Plattin focus has the following characteristic determinants (other than Pattern or Phase determinants) : stone box graves without rock covers containing single extended burials with grave furniture near an area containing pottery apparently left as a part of a ceremony carried out in conjunction with the funeral rite. Burials are in cemeteries adjacent to but not in the villages. There are three types of rectangular houses. Small rectangular houses were made with slightly depressed floors next to large rectangular houses with walls having post supports which were set in ditches and houses made by placing poles with chisel shaped bottoms on the habitation surface to support wattlework. Roofs were of thatch. Fireplaces were two or three small bowl shaped clay pits next to each other and also outside the houses. Ceremonial pottery from the mounds and the burials is Imperial Plain ware consisting of small olla or jar forms with loop handles, some water bottle pots and some plates. The utilitarian ware found mainly in the village is of Plattin Clay Tempered and is in the form of common bowls and large jar forms usually with angular shoulders.

There is a small amount of Imperial Plain textile marked pottery. Other characteristics are flaring bitted highly polished thin flint celts, bowl pipes on stems of red claystone, bowl pipes and bent tubular pipes of Imperial Plain ware, finely chipped stemmed projectile points, biconcave discoidals, polished celts, polished chisel celts, perforated mussel shell hoes, coarsely chipped hoes and polished bone awls, one flattened at one end and carved into the outline of an eagle. (See Plate XII B). There is unmistakable influence of the Woodland in the Boyce focus as indicated by the preponderance of cord marked ware in the village and the coarse chipping observed on some of the flint implements.

The Kimmswick focus has the following characteristic determinants: extended human burials in shallow pits sometimes surrounded by sherds and sometimes with grave furniture, burials in the village debris, rectangular houses with depressed floors with ditches below the edge of the floors for inserting wall posts, large rectangular houses with center posts, sherd and clay lined shallow cooking basins or large common bowls set in shallow excavations adjacent to irregular shaped concave burned clay fireplaces, very large amounts of Imperial Plain pottery and some Crystal City Cord Marked pottery. A great deal of the former ware from the large common bowls is textile impressed giving the evidence of several weaves.[1] We have hesitated in calling these large bowls salt pans because we are not yet certain that they were used for salt manufacture.

The most common pottery shapes are "seed" bowls, large deep bowls, common bowls, effigy flange bowls, plates and olla or jar forms. Small water bottles and small ollas have been found with the burials. Etched designs on the upper surfaces of plate rims and red slips are the most common forms of decoration. The latter is particularly prevalent. There are several lip forms on the large open bowls. There are also notched small triangular projectile points, finely chipped expanded base

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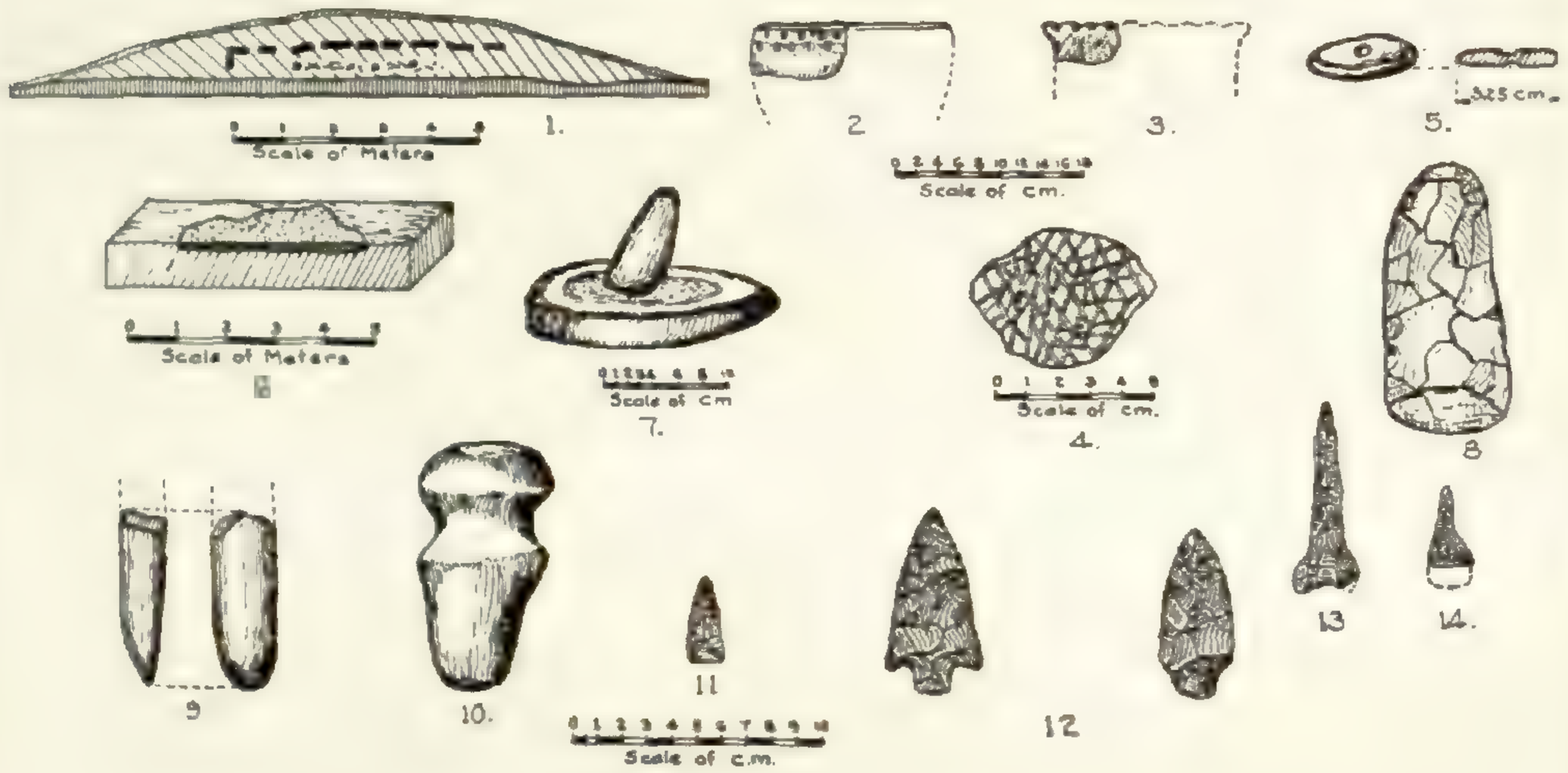
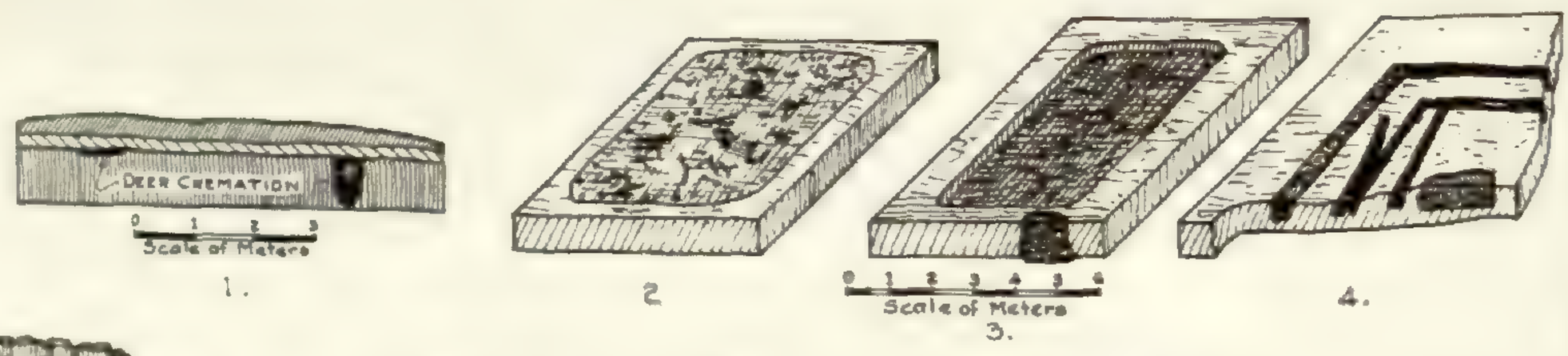
[1]A special study is being made of these textiles. This study is to appear in the January 1942 issue of *American Antiquity*.

drills, long and short polished awls of deer bone, very fine needles without eyes made from slivers of bone, flattened polished bones, chisel shaped smooth edge bones, large flat disc shaped grinding stones, large mushroom shaped pottery "trowels," perforated pottery discs, small shell beads, perforated shell hoes, columellae of Busycon shells, pitted sandstone drill holder and sandstone "arrowshaft straighteners." (See Plate XIII).

It is not certain to which aspect the Jenni mound must be assigned. The mound was not found in immediate association with the village, whereas the mound at the Herrell component was in the village. Other traits found from this mound tie up with the Plattin focus, namely stone box graves which are without burial furniture and bundle burials similar to one of the stone box graves from the Boyce focus and deep narrow ceremonial pit below center of mound. As in the case of the Boyce mound there was a deep refuse pit below the mound base. The lack of Plattin Clay Tempered ware, the dominance of Imperial Plain ware and an effigy flange indicated Kimmswick affiliation. The two color mound fill and the burned ceremonial building at the base of the mound with the extended burial under it cannot be linked with either the Plattin or Kimmswick focus, but the total lack of Plattin Clay Tempered ware tends to tie the mound in with the Kimmswick focus. However, since we found only a few sherds from the Jenni mound we cannot be sure which focus to tie the mound up to.

We have a similar situation at the Schock mound. The rectangular flat limestone platform on which the fragmentary bundle burials were placed looks Middle Mississippi but the oval vault over the edge of the platform and burials looks Woodland. The isolation of this mound from a village, the presence of Imperial Plain pottery only and the deep narrow refuse pit below the mound base plainly indicates that possibly both the Jenni and the Schock mound were left by the same group. Inasmuch as we have only the ceremonial component represented at these two sites we are not yet in a position to give aspect status to either mound. However, it looks very much as if





PLATES XII A and XII B

A. Traits Found from Festus Focus of the Woodland Phase with Mississippi Inffuence

B. Traits Found from Plattin Focus of Middle Mississippi Phase

DESCRIPTION OF OBJECTS OF FESTUS FOCUS ILLUSTRATED IN PLATE XII A

1. Partially Articulated Human Burials Under Rocks in Mound.
2. Thumbnail Depressions on Rim of Amphora Pot.

3. Cord Wrapped Stick Impressions on Lip of Amphora Pot.
4. Sherd with Cord Roughened Surface.
5. Crude Pottery Disc with Centered Depressions on Both Surfaces.
6. Irregular Fireplace.
7. Mortar and Pestle.
6. Irregular Fireplace
8. Chipped Adze.
9. Ground Chisel Celt.
10. Grooved Ax of Hematite.
11. Small Isosceles Triangular Projectile Point.
12. Stemmed Projectile Points.
13. Winged Drill.
14. Expanding Base Drill.

DESCRIPTION OF OBJECTS OF PLATTIN FOCUS ILLUSTRATED IN PLATE XII B

1. Deer Cremation next to Deep Cremonial Pit Below Mound.
2. Rectangular House made by Inserting Poles in Habitation Levels Below Corner of Mound.
3. Rectangular Shallow Pit House and Refuse Pit.
4. Rectangular House Remnants made by Inserting Posts in Ditches giving a kind of Palisaded Effect.
5. Stone Box Grave with Grave Furniture.
6. Flaring Mouthed Olla or Jar.
7. Beanpot Handle.
8. Small Olla or Jar with Two Loop Handles.
9. Water Bottle.
10. Undecorated Plate.
11. Olla or Jar Form with High Necks and Angular Shoulders.
12. Shallow Bowl.
13. Flaring Bitted Polished Spud of Chert.
14. Biconcave Discoidal.
15. Thick Sandstone Discs with Centered Depressions.
16. Ground Chisel Celt.
17. Celt.
18. Bowl Pipe of Red Claystone Mounted on Stem.
19. Perforated Mussel Shell Implement.
20. Bowl Pipe of Pottery for Reed Stem.
21. Bent Tubular Pipe of Pottery.
22. Finely Chipped Projectile Point with Slight Indication of a Stem.
23. Small Isosceles Triangular Projectile Points.
24. Thumbnail Scraper.
25. Expanding Base Drill.
26. Chipped Knife with Convex Base.
27. Portion of Knife
28. Coarsely Chipped Hoe with Cutting Edge Polished Through Use.
29. Awl Made of a Bone Sliver.
30. Polished Bone Point with Perforated Eagle Effigy at Base.

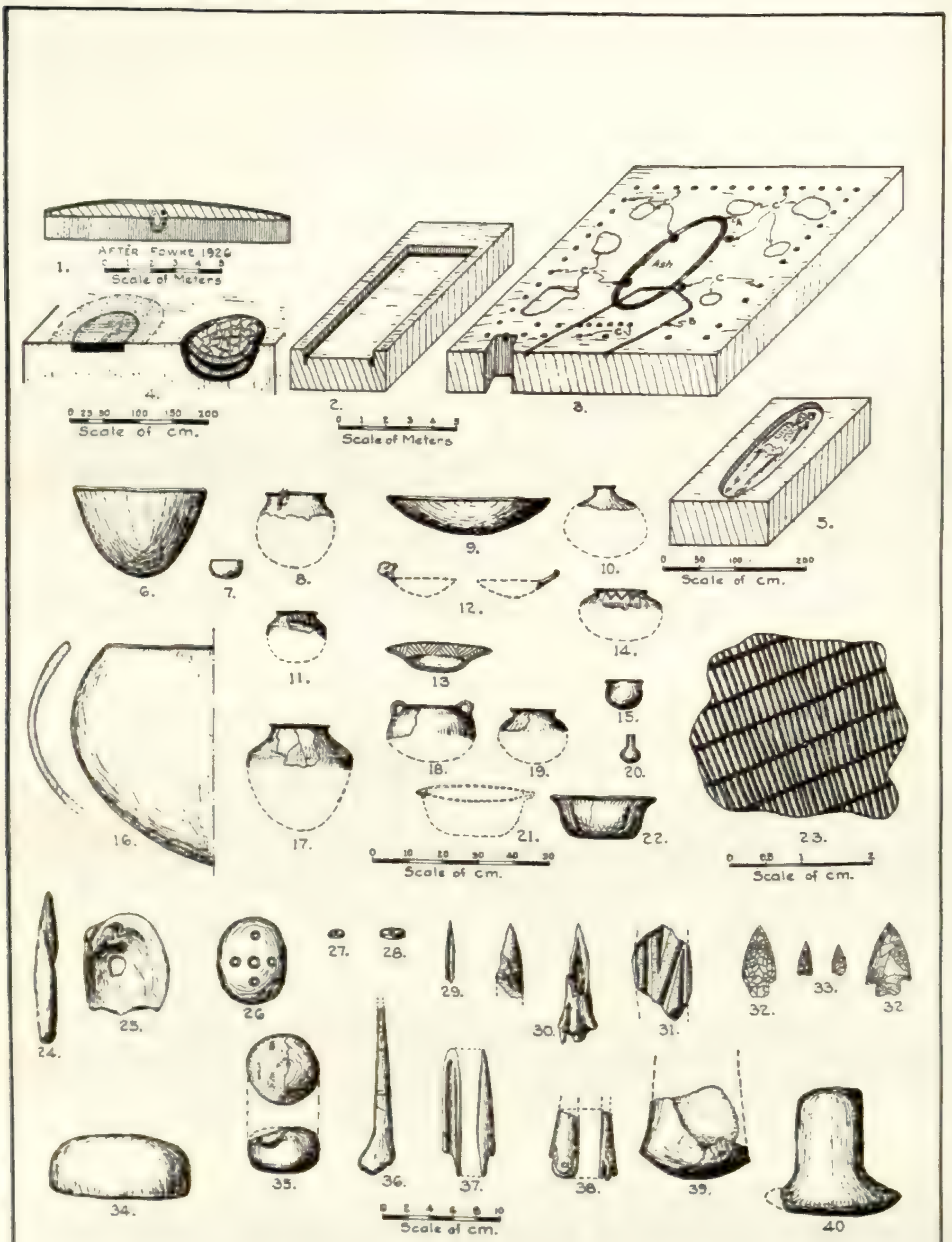


PLATE XIII

Traits Found from Kimswick Focus of Unknown Aspect of Middle Mississippi Phase

DESCRIPTION OF OBJECTS OF KIMMSWICK FOCUS

ILLUSTRATED IN PLATE XIII

1. Low Mound Containing Human Bones Over Ceremonial Pit.
2. Pit House with sub-floor Ditches for Narrow Wall Supports.
3. Large Rectangular House made by Inserting Posts in Ground with Four Center Posts and Individual Family Cooking Basins. (C) Large Firepit (A) of earlier date than (C), and Wall Outline of Third Structure (B).
4. Typical Clay and Sherd Lined Basin used for Cooking and Refuse.
5. Extended Burial in Shallow Pit with Grave Furniture.
6. Common Bowl with Tapering Bottoms.
7. Cup Form of Pot.
8. Olla or Jar with Two Animal Effigy Handles
9. Large Shallow Bowl often Textile Impressed.
10. Narrow Necked Olla Form with Slightly Flaring Lip.
11. Olla Pot with Black Polish Finish and Trailed Design on Shoulder.
12. Effigy Flange Bowls.
13. Plate Form with Incised Chain of Triangular Decoration on Upper Surface of Rim.
14. Olla or Jar Form with Incised Angular Meander Decoration on Shoulder.
15. Olla or Jar with Two Loop Handles.
16. Large Seed Bowl Pot.
17. Olla or Jar Form with Long Neck and Angular Shoulders.
18. Olla or Jar Form with Loop Handles extending above Lip Surface.
19. Olla or Jar.
20. Water Bottle.
21. Lip Flange.
22. Bowl with Flaring Lip.
23. Textile Impressed Sherd.
24. Columella of Busycon.
25. Perforated Mussel Shell Implement.
26. Thin Concave Pottery Disc with Multiple Perforations.
27. Crinoid Stem Bead.
28. Shell Disc Bead.
29. Bone Needle without Eye.
30. Bone Awls of Deer Ulnae.
31. Arrowshaft Straightener.
32. Finely Chipped Stemmed Projectile Points.
33. Small Isosceles Triangular Projectile Points.
34. Grinding Stone.
35. Polished Discoidal.
36. Long Bone Awl.
37. Bone Spatula.
38. Smoothed Bone Implement.
39. Flaring Bitted Celt.
40. Large Mushroom Shaped Trowel of Red Claystone.

the Jenni mound was pure Middle Mississippi, whereas the Schock mound is Middle Mississippi mixed with Woodland.

The following traits serve to distinguish the Kimmswick focus from the Plattin focus and are diagnostic:

Kimmswick Focus	*Plattin Focus*
Large numbers of shallow round pits containing large bowls lined with pottery sherds intercalated with clay layers used for cooking and as refuse containers.	Large numbers of refuse pits with flat bottoms containing quantities of decayed vegetable matter.
Oval or irregular baked clay fireplaces.	Small round depressed baked clay fireplaces.
Rectangular structures with one to four center supports.	Wedge bottoms to house posts where small uprights were used.
Small pit structures with thin subfloor wall ditches.	Small pit houses without thin subfloor wall ditches.
Small grained corn.	Large grained corn.
Low mounds over shallow ceremonial pits lined with clay and containing human bones above pit.	Cremated deer and human burials next to deep narrow ceremonial pits at the base of low mounds.
Extended human burials directly under the surface in shallow pits sometimes lined with pottery sherds.	Extended human burials in stone box graves.
Burials in village.	Burials in cemeteries adjacent to but not in village.
Flaring bitted celts.	
Use of Busycon columellae.	
Pottery trowels of both red claystone and pottery.	

Kimmswick Focus [Con't.]	*Plattin Focus [Con't.]*
Tremendous majority of Imperial Plain on both village and ceremonial sites.	Use of Plattin Clay Tempered ware on village and Imperial Plain on ceremonial sites.
Large numbers of textile marked sherds.	Textile marked pottery infrequent.

Certain traits and components that we have found are capable of being compared with cultural complexes described elsewhere. The Festus focus has some resemblances to Fowke's Missouri Valley bluff mounds sucn as hematite worked into grooved axes, winged drills and expanded base drills, large stemmed projectile points, a minority of coarsely chipped small isosceles projectile points, cord marked grit tempered ware, vertical rims sometimes with slightly flaring lips, rock pavements with partly articulated burials in low mounds, rock placements around burials in mound fill[1] and human bones scattered in the mound fill.

From the McCormack component of the Boyce focus is a pipe on a projecting stem of red claystone similar to a few pipes from Oneota aspect. From the same component is a very thin flaring bitted celt of polished chert that has analogies from Lower Mississippi Pattern components from Texas and Oklahoma.

The Middle Mississippi pottery, our Imperial Plain, is found in several forms similar to Middle Mississippi pottery from Cahokia and Moundville. Among other Middle Mississippi traits stone box graves are found with the Tennessee-Cumberland aspect of the Middle Mississippi phase and with the Madisonville focus of the Fort Ancient aspect of the Upper Mississippi phase as well as the Etowah focus of the Middle Mississippi phase. The etching on the upper surfaces of plates is found occasionally on pottery in Middle Mississippi sites but according to Dr. Thorne Deuel this decorative technique seems to be characteristic of the Lower Mississippi pattern.

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[1]Archaeological Inves. in Boone County, Mo., *The Missouri Archaeologist,* Berry, J. B., Wrench, J. E., Chapman, C., Seitz, W., Sept. 1938.

Thus far no Oneota pottery or Hopewellian pottery has been found in this area. The Middle Mississippi shell tempered pottery recently mentioned by Drs. Dellinger and Dickinson has limited similarity to our Imperial Plain ware but is probably considerably softer.[1]

Effigy bottles, bowls with annular ring bases and tripod pots are absent. Ollas, or jars, bowls and water bottles are similar to East Arkansas forms. However, there is no indication of Deasonville, Coles Creek or Marksville ceramic influence. The Plattin Clay Tempered ware from the Plattin aspect is certainly suggestive of southern influence according to Dr. James Griffin's pottery analysis report. The presence of large numbers of sherds from the Kimmswick focus with red slipped surfaces is suggestive of the Arkansas River focus of Eastern Arkansas aspect of Middle Mississippi phase.

Our St. Jo Polish Plain is typical of the thin hard finely shell tempered ware from Cahokia where it is called Powell Polish Plain.

Both the Kimmswick and the Plattin focus have traits that can be linked with aspects of the Upper, Middle and Lower Mississippi phases. Those traits that are found mainly with one or more Upper Mississippi aspects include pipes for reed stems, pipes with projecting stems made of claystone, polished wedge shaped bone tools, arrowshaft straighteners and considerable variation in olla or jar size. Those traits that are commonly found with the Upper and Middle Mississippi phases include biconcave discoidals, polished celts without flaring bits, small isosceles projectile points finely chipped, cut shell disc beads perforated centrally, bone awls and needles, incising on shoulders of ollas or jars, lip flanges, more than one pottery ware, extended human burials with or without grave furniture and use of stone box graves. Those traits that are commonly found with the Middle

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[1]Dellinger, S. C. and Dickinson, S. D., "Possible Antecedents of the Middle Mississippian Ceramic Complex in Northeastern Arkansas," *American Antiquity* Vol. VI, No. 2, Oct. 1940, pp. 133-147.

Mississippi phase include chipped hoes, columellae of the Busycon shell used either as an implement or an ornament, perforated or cut mussel shells used as spoons or hoes, several pottery shapes, use of clay slips, pottery "trowels," St. Jo Polish Plain ware, tendency to use smaller thinner ware for burials than for everyday use, pottery pipes including the obtuse angle and bowl form for use with reed stem, large numbers of textile impressed pottery sherds with more than one type of weaving and more than one rectangular house type. Two traits are linked with the Middle or Lower Mississippi phase, namely etched designs and large square buildings with four central posts.

It is interesting to note that neither the Kimmswick nor the Plattin has yet been shown to have been historic in this area.

VII. SUMMARY OF CULTURAL PHASES

PROBABLE RELATIVE SEQUENCE[1]

The following are outlines of the probable sequence of components investigated during the 1939-40 field season:

Woodland with Mississippi influence phase

$J^{o}1$, $J^{o}35$[2], $J^{v}5$, $J^{s}7$ two late occupations, $J^{s}30$ late occupations,* $J^{s}3$ latest occupations.*

Middle Mississippi phase

$J^{o}40$, $J^{o}60$[2], $J^{v}32$[2], $J^{v}55$[2, 3], $J^{c}21$, $J^{s}7$ one late occupation.*

Woodland phase

$J^{v}62$, $J^{o}57$ primary occupations and two intrusive burials.* $J^{s}7$ middle occupations, $J^{s}30$ earliest occupation,* $J^{s}3$ earliest occupations.*

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[1]Actual stratigraphic sequence indicated by asterisks.

[2]Charred wooden beams have been sent to the dendrochronological laboratory at the University of Chicago for analysis.

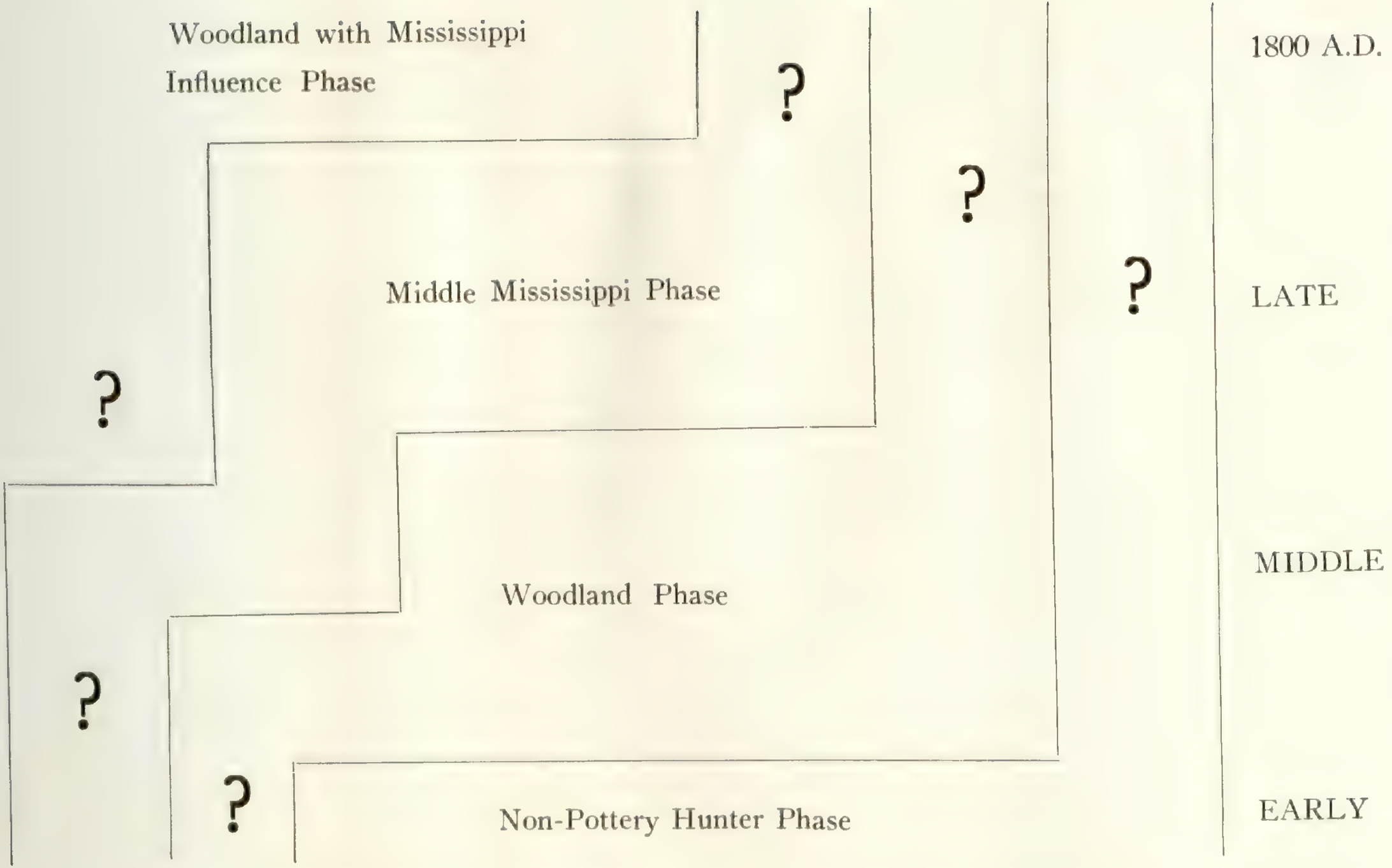
[3]According to a communication from Mr. John Bennett of the University of Chicago, several of the traits of the Kimmswick focus suggest generalized traits found in supposedly early manifestations of the Middle Mississippi phase on the Tennessee River and Central Georgia. These are: loop handles on jars; preponderance of heavy utilitarian pottery, frequently with conoidal bases; large, square, small-post structure; small, rectangular, domestic structure; pit-burials with red ocher in floor below mound; small-grain corn. Against these presumably "early" traits occur effigy flanges on bowls, engraved plate rims, shell artifacts, and other elements usually considered comparatively late in the Middle Mississippi phase.

Non Pottery Hunter phase
Js7 earliest occupations.*

No cultural component or focus has yet been excavated so that a complete picture of a community cannot be given. The nearest approach to this optimum condition are the Plattin and Kimmswick foci. Both of these foci have house traits, village traits and ceremonial traits. The architecture and house life is fairly well known. The costume and dress is indicated by the charred woven clothing from the Jenni mound which belongs to either the Plattin or Kimmswick focus. The ceremonial complex is indicated by the mode of burial mounds, and by the grave furniture. The military and hunting complex is fairly well indicated by the relative rarity of flint projectile points, pointing toward the peaceful nature of these agricultural peoples. The agricultural life is well indicated by remnants of charred corn and large amounts of dark decayed vegetable matter from the Plattin focus. The artistic life seems to have been poorly represented if we can judge by the almost general lack of ornaments and beads. The pottery complex is the most dominant characteristic of both foci.

The Festus focus is almost entirely represented by the ceremonial complex, while the early Woodland is only indicated by village fireplaces and flint implements, probably weapons.

The earliest group represented at the Hidden Valley shelter is indicated only by flint implements which were probably used for hunting and war-making activities.



Probable Relative Sequences of Cultural Phases in Jefferson County, Mo.

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